Towards a Decision Support Method for Trade-off Analysis Considering Cost, Risk, and Quality

Master Thesis by

Avjot Garcha Singh

Department of Informatics
Faculty of Mathematics and Natural Sciences
University of Oslo

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In the memory of my beloved grandfather

S. BALWANT SINGH GARCHA

(1928 - 1996)

Abstract

Before adopting or implementing new technology solutions, there is a need for a decision support method which enlightens the effects of the implementation of the various decision alternatives with respect to cost, risk, and quality aspects. We have proposed a decision support method for trade-off analysis considering three aspects: cost, risk, and quality. By cost we mean the cost of implementing the various decision alternatives. By risk we mean the risks associated with the implementation of the decision alternatives. By quality we mean the effect on overall system quality by implementing the various alternatives. The decision making method involves a process, an approach to modeling, and an approach to visualizing the decision alternatives and their overall performance with respect to cost, risk, and quality aspects.

We have evaluated the decision making method through a case study with respect to a set of pre-defined success criteria. Apart from the case study, the evaluation involved thought experiment, observations made during the analysis, exemplifications, written and verbal feedback.

The outcomes and results of the evaluation indicate practical feasibility of the proposed method in a realistic context. In addition, the evaluation has provided useful insights into strengths and weaknesses of the method and suggested directions for future research and improvements. This thesis presents the decision making method, and its evaluation.

Keywords: *Decision making, decision support method, trade-off analysis, cost analysis, risk analysis, quality analysis*

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Oslo, May 1st 2014

Avjot Garcha Singh

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Chapter 1

Introduction

Imagine an enterprise wanting to make changes to their information system architecture in order to enhance and improve the security. The enterprise has for instance allocated three possible decision alternatives that might be beneficial regarding security of their information system. However, what is the cost of the decision alternatives, what risks are associated with the decision alternatives, and which effects do the three decision alternatives have on the quality of the overall system? Such decisions might be quite crucial in Information Technology scenarios.

We propose a decision making method that combines and visualizes three aspects: cost of implementing the decision alternatives, the risks associated with the decision alternatives, and the overall effect on system quality. By applying our decision making method, an enterprise might have better understanding of the various proposed changes, and thus be able to make more informed decisions.

The uniqueness of our proposed decision making method is its overall simplicity. The decision making method is quite straightforward with defined and structured stages taking into account resource limitations. At the same time, the method offers a holistic approach in the sense that it takes into account cost, risk, and quality in the form of a consolidated view. By consolidated view we mean the overall picture of the decision alternatives and their performance with respect to cost, risk, and quality aspects. Such a method may be helpful in the field of Information Technology, where decisions involving assessment of risks and identifications of cost and quality elements are too difficult to predict.

As pointed out by Ravindran [1]: “There is no guarantee that a decision will always be good when uncertainties are present, but the chances of a decision being good increase significantly when the decision process is good. Making good decisions takes time and effort but the rewards are worth the investment. This is true for decisions in everyday life as well as those one wrestles with in their work. To help one make good decisions consistently, a decision maker needs to develop a good process, apply the process to all decisions, be flexible, adjust decisions as time and information become available, and enjoy what they are doing; then good decisions will occur".

We have evaluated the decision making method through a case study with respect to a set of pre-defined success criteria. Apart from the case study, the evaluation involved thought experiment, observations made during the analysis, exemplifications, written and verbal feedback. The decision making method was developed and improved during the case study research. Results indicate that the method proposed facilitates decision making within Information Technology. In additional, the evaluation has provided useful insights into strengths and weaknesses of the method and suggested directions for future research and improvements. This thesis presents the developed decision making method, and reports on the results of its evaluation.

1.1 Decision making

Everyone encounters decision making problems on a daily basis. Some decisions are quite easy to make, but some decisions can be quite problematic and challenging. The common denominator for all decision making problems are that the decisions are often made based on satisfaction for where the decision criterion is maximized or minimized. However, decision scenarios usually involve more than one decision criterion. In that manner, the decision maker often needs to compensate between the various decision criteria. Multiple criteria decision making (MCDM) involves solving decision making problems with multiple decision criteria [1].

As pointed out by Ravindran [1]: "In single criterion decision problems, the "best" solution is defined in terms of an "optimum solution" for which the criterion value is maximized (or minimized) when compared to any other alternative in the set of all feasible alternatives". In a perfect decision making scenario a decision alternative stand out by satisfying all decision criteria. However, it is usually quite rare that a decision alternative satisfy all decision criteria. In most of the cases, the decision maker usually selects a decision alternative based on preferences and priorities of the decision criteria.

In that manner, it is often necessary to perform a thorough analysis of a complex decision making scenario. "Decision analysis can thus be defined as the process and methodology of identifying, modeling, assessing, and determining an appropriate course of action for a given decision problem. This process often involves a wide array of tools and the basic approach is generally to break the problem down into manageable and understandable parts that the decision maker can comprehend and handle. It is then necessary to take these smaller elements and reconstitute them into proper solution for the larger original problem" [1].

1.2 Objective

Analysts in the field of Information Technology often have to make vital decisions regarding risk, investment, cost, profit, and quality. When adopting or implementing new technology features to already existing systems, there are several decisions to make. Clients often seek information on how their information system will be affected and if it will be beneficial to invest in new technology solutions. In that manner, the analysts need strong documentation regarding the changes caused by the deployment of new technology features. However, there is no detailed information regarding the employment of the technology alternatives, and it is therefore difficult to distinguish the alternatives and the benefits they would provide. To best of our knowledge, there is no such decision making method that takes into account the three aspects of cost, risk, and quality of the proposed decision alternatives. A method that combines and visualizes the cost from implementing the various alternatives, the risks associated with the various alternatives, and the effect on system quality, might provide valuable information to decision making situations.

There are actually cases where wrong decisions have had fatal consequences financially. According to Brecht and Nowey [2]: "Economic aspects of information security are of growing interest for researchers as well as for decision makers in IT-depending companies". Making an investment requires strong foundation based on risks attached to the action and what kind of effect it would have on the overall quality of the system. When this is said, it is not assumed that a method that combines the three factors of cost, risk, and quality will provide the correct decision in every decision making scenario.

However, it is assumed that such a method will be a helpful guidance and support towards efficient decision making. In that manner, such a method should provide help and guidance for a decision maker to create adequate decisions in Information Technology situations.

In summary, the main objective of this thesis is to provide a decision support method considering three aspects: cost of implementing the decision alternatives, the risks associated with the decision alternatives, and the overall effect on system quality. The proposed decision making method should be:

- useful in the sense that it facilitates decision making;
- cost-effective; and
- comprehensible for the stakeholders involved.

By useful we mean that the decision making method facilitates decision making with structured guidance and model certainty. By cost-effective we mean that the decision making method should be applicable in an industrial context and be effective without wasting time or effort. By comprehensible we mean that the stakeholders should be able to interpret the method in a correct manner. Hence, the decision making method should be straightforward and easy to use.

1.3 Contribution

The main contribution of this thesis is a decision making method for trade-off analysis considering cost, risk, and quality aspects. The term *method* is defined as "a particular procedure for accomplishing or approaching something, especially a systematic or established one" [3]. Our proposed decision making method combines and visualize the cost from implementing the various alternatives, the risks associated with the various alternatives, and the effect on system quality. With respect to our proposed decision making method, in this thesis we have primarily focused on the following three artifacts:

1. The process of the decision making method
2. The approach to modeling in the decision making method
3. The approach to visualizing the decision alternatives

We consider the artifacts to be the main building blocks of our proposed decision making method. The artifacts are based on the needs and requirements derived from the evaluation of our decision making method.

1.3.1 The process of the decision making method

The process of the decision making method aims to guide the analyst through a range of activities or tasks in order to gain a structured overview of aspects relevant for the decision alternatives. Hammer and Champy [4] describe a *process* as "collection of activities that take one or more kinds of input and create an output that is of value to the customer". In that manner, we can understand a process as a sequence of actions carried out by certain stakeholders.

The process of the decision making method aims to facilitate and guide the analyst to systematically conduct the decision making method. This implies that the process will need clearly identified inputs in order to create sufficient outputs. The inputs in this case should be based on documentation, measurements, historical data, guidance, support, and expert judgements provided by the domain experts. The process of the decision making method consists of four phases:

1. **Quality Analysis**: The Quality Analysis phase involves the development of quality level estimates associated with the various decision alternatives.
2. **Risk Analysis**: The Risk Analysis phase involves the development of risk representations associated with the implementation of the various decision alternatives.
3. **Cost Analysis**: The Cost Analysis phase involves the development of cost level estimates of the information system after the implementation of the various decision alternatives.
4. **Decision Making**: The Decision Making phase involves integration and visualization of the overall performance of the decision alternatives with respect to cost, risk, and quality aspects.

The process leads to the development of models containing cost, risk, and quality-related information that contribute to making adequate and sufficient decisions related to the deployment of the various decision alternatives.

The stakeholders involved are: the analyst, the domain experts, and the decision maker. The analyst is the one that will be conducting the decision making method and documenting the results. The analyst might not have complete insight into the target system under analysis, but should however understand its primary properties to be able to conduct the analysis. Hence, the analyst is expected to tightly collaborate with the domain experts. The domain experts are expected to have expertise on the target system under analysis, and will thus provide helpful input during the analysis. The domain experts should also evaluate and validate the end results. The decision maker will basically apply the results conducted by our process. According to Ravindran [1], a decision maker is defined as "the entity responsible for making the decision. This may be a single person, a committee, company, and the like".

1.3.2 The approach to modeling in the decision making method

The approach to modeling in the decision making method aims to provide comprehensible support for the development of the models containing cost, risk, and quality-related information. The proposed decision making method offers notation, terminology, and guidance for developing these models. The approach to modeling in the decision making method makes use of existing modeling techniques and concepts. The adopted modeling techniques and concepts are well-known and chosen with objective to be familiar and comprehensible to non-technical users. The models aim to capture relevant information considering cost, risk, and quality aspects. Moreover, the models intend to provide common understanding of the target system under analysis with respect to cost, risk, and quality aspects.

In addition, our approach to modeling provides a functional fulfillment analysis. By functional fulfillment analysis we mean the analysis of (1) degree of fulfillment of functional requirements with respect to objective, and (2) degree of overlap between the decision alternatives with respect to the functional part of objective. The degree of fulfillment reflects the coverage of functional features related to the various decision alternatives with respect to the objective. By overlap we mean the association, interplay, and relationship between the various decision alternatives. The approach to modeling offers notation, terminology, and guidance for expressing the degree of fulfillment and the degree of overlap. Our proposed decision making method makes use of the notion of feature modeling [5] to express the degree of fulfillment and the degree of overlap. Feature diagrams have a hierarchical tree structure containing features, characteristics, and aspects associated with the object in question [5]. Feature diagrams are useful in the sense that they provide insight into the various features and functionalities implemented by the various decision alternatives. Our experience is that the functional fulfillment analysis provides important information regarding the performance of the decision alternatives.

The target groups of the approach to modeling in the decision making method are primarily the analyst and the domain experts. The approach to modeling is used throughout the phases of the decision making process. The models are expected to be developed by the analyst in close collaboration with the domain experts. The models are used to analyze the overall performance of the decision alternatives in the final stage of the decision making process.

1.3.3 The approach to visualizing the decision alternatives

The approach to visualizing the decision alternatives aims to provide comprehensible support for model-based selection of decision alternatives. Model-based selection involves selection of decision alternatives through visualization. Our approach to visualizing the decision alternatives makes use of graphical visualization techniques and concepts in order to facilitate decision making scenarios. The approach to visualizing the decision alternatives is employed during the final stage of the decision making process.

Model-based decision making is useful in the sense that it provides comprehensible and graphical insight into the performance of the various decision alternatives. Our approach to visualizing the decision alternatives provides one viewpoint for decision making and supports multiple criterion decision problems. Our proposed approach visualizes the decision alternatives with respect to cost, risk, quality, and degree of fulfillment. The decision maker will thus be able to distinguish the decision alternatives based on their benefits and drawbacks with respect to the selection criteria.

The target groups of the approach to visualizing the decision alternatives are primarily the analyst and the decision maker. The analyst will use the approach to analyze, present, and display the overall performance of the decision alternatives. The decision maker will basically apply the results conducted by our proposed decision making method.

1.4 Structure of the thesis

Chapter 1 **Introduction**	Chapter 1 motivates the need for a decision support method for trade-off analysis considering cost, risk, and quality aspects. In addition, the chapter presents the main objective and contribution of this thesis.
Chapter 2 **Characterization of needs**	Chapter 2 presents the set of pre-defined success criteria with respect to our artifacts that should be fulfilled in order to achieve the overall objective.
Chapter 3 **Research method**	Chapter 3 presents the research method applied in the research of this thesis.
Chapter 4 **State of the art**	Chapter 4 presents the related state of the art for this thesis.
Chapter 5 **An overview of the approach and its artifacts**	Chapter 5 provides an overview of the decision making method and its artifacts. In addition, we explain the relation between the artifacts.
Chapter 6 **Evaluation of the artifacts**	Chapter 6 presents the evaluation of our artifacts.

Chapter 7 **Evaluation with respect to the success criteria**	Chapter 7 discusses to what extent the success criteria have been fulfilled by the specific artifact in question.
Chapter 8 **Threats to validity and reliability**	Chapter 8 addresses the matters that might have influenced the validity and reliability in our research.
Chapter 9 **Conclusions and future work**	Chapter 9 presents conclusions with respect to the contribution of the research and suggests possible objectives of further work.

Chapter 2

Characterization of needs

In the previous chapter we motivated the need for a decision support method for trade-off analysis considering cost, risk, and quality aspects. According to the International Organization for Standardization [6], quality is defined as "the degree to which a set of inherent characteristics fulfills requirements". Risk is defined as "the likelihood of an unwanted incident and its consequence for a specific asset" [7]. By cost we mean the total operating cost of the target system after the implementation of the decision alternatives.

In this chapter we refine the objective for the decision making method into a set of success criteria with respect to the artifacts presented in the previous chapter. Section 2.1 presents the stakeholders involved and their role throughout the decision making method. In section 2.2 we characterize the success criteria for each artifact that should be fulfilled in order to achieve the overall objective.

2.1 Stakeholders

This section presents the stakeholders involved and their role throughout the decision making method. The stakeholders include the analyst, the domain experts, and the decision maker.

The *analyst* is the one that will be conducting and performing the decision making method. The analyst leads the decision making process, develops the models, and documents the results. The analyst might not have complete insight into the target system under analysis, but is expected to be able to understand its primary properties. The analyst will tightly collaborate with the domain experts throughout the decision making method.

The *domain experts* have expertise on the target system, and will thus provide helpful and valuable input throughout the analysis. The domain experts also contribute to evaluation and validation of the models and the end-results.

The *decision maker* will apply the results conducted by the decision making method. The decision maker might be represented by the management of a firm, organization, or enterprise that will request the results conducted by the decision making method. It is expected that the decision making method will facilitate the decision maker in making more informed and sufficient decisions.

2.2 Success criteria

In the following we outline and specify the success criteria for the decision making method with emphasize on the artifacts presented in Section 1.3: (1) the process of the decision making method, (2) the approach to modeling in the decision making method, and (3) the approach to visualizing the decision alternatives. We consider the three artifacts to represent the main building blocks of the decision making method. As explained in Section 1.2, our overall objective is to provide a decision support method considering three aspects: cost of implementing the decision alternatives, the risks associated with the decision alternatives, and the overall effect on system quality. The decision making method should be:

- useful in the sense that it facilitates decision making;
- cost-effective; and
- comprehensible for the stakeholders involved.

In the following sections, we specify a set of success criteria with respect to our overall objective regarding the artifact in question.

2.2.1 The process of the decision making method

The process of the decision making method aims to facilitate and guide the analyst to systematically conduct the decision making method. Considering our overall objective, the process of the decision making method should be applicable in an industrial context within limited resources. The analyst is the one that will be conducting and performing the process. The decision maker will apply the results conducted by the process of the decision making method. In that manner, the process of the decision making method should be straightforward, easy to perform, and sufficiently comprehensible to the stakeholders. Hence, we specify the following set of success criteria with respect to the process of the decision making method:

Success criterion 1 - *The process of the decision making method facilitates the making of informed decisions.*

The process of the decision making method aims to guide the analyst through the decision making method. The process of the decision making method should therefore provide stepwise actions to be conducted by the analyst during the analysis. The analyst is expected to have expertise in the decision making method. The decision maker should be able to apply the results conducted by the process in decision making. By providing stepwise guidance and support, the process of the decision making method should be able to facilitate the making of informed and sufficient decisions.

Success criterion 2 - *The process of the decision making method can be applied in a real-life setting within limited resources.*

This criterion addresses the feasibility of conducting the process within limited resources in a real-life setting. The analyst should be able to conduct and perform the process within allocated resources in a realistic industrial context with acceptable effort. This also implies that the process should be cost-effective.

Success criterion 3 - *The process of the decision making method is sufficiently comprehensible to the stakeholders.*

This implies that the process of the decision making method is comprehensible and easy to understand by the stakeholders involved: the analyst, the domain experts, and the decision maker. The stakeholders should be able to interpret the process in a correct manner. The process should facilitate a common understanding of the decision making problem in question.

2.2.2 The approach to modeling in the decision making method

The approach to modeling in the decision making method aims to provide comprehensible support for the development of the models containing cost, risk, and quality-related information. The models containing cost, risk, and quality-related information are used by the decision maker to analyze the overall performance of the decision alternatives. In that manner, the approach to modeling in the decision making method should provide sufficiently correct, certain, and expressive set of models. The approach to modeling in the decision making method should be capable of capturing relevant information considering cost, risk, and quality aspects. Domain experts with various technical backgrounds are expected to provide input during the development of the models. Considering the stakeholders involved, the approach should be comprehensible and easy to use. Hence, we specify the following set of success criteria with respect to the approach to modeling in the decision making method:

Success criterion 4 - *The approach to modeling in the decision making method provides sufficiently correct and certain set of models.*
This implies that the set of models are unbiased as well as sufficiently accurate and precise for the purpose intended, and should substantiate and support the decisions made by the decision maker. In that manner, uncertainties must be taken into account. The uncertainties involved must be reported and managed properly.

Success criterion 5 - *The approach to modeling in the decision making method provides sufficiently expressive set of models.*
This implies that the models should provide sufficient understanding of the target system under analysis and the decision alternatives in terms of cost, risk, and quality aspects. The models should be able to sufficiently express the relevant information for the intended purpose.

Success criterion 6 - *The approach to modeling in the decision making method is sufficiently comprehensible to the stakeholders.*
This implies that the models are easy to understand by the stakeholders involved: the analyst, the domain experts, and the decision maker. The models should facilitate a common understanding considering the decision making problem in question. The

approach to modeling in the decision making method should ensure that domain experts with various technical background should be able to develop the models. The domain experts are expected to have expertise on the target system under analysis, and should thus be able to contribute to modeling, agree upon a common set of the models, and approve them. Indicators for this include involvement of the stakeholders, agreement upon the models, ability to use the models correctly, correct interpretation, and consistent estimates.

2.2.3 The approach to visualizing the decision alternatives

The approach to visualizing the decision alternatives aims to provide comprehensible support for model-based selection of decision alternatives. In that manner, the approach to visualizing the decision alternatives should provide graphical insight into the overall performance of the various decision alternatives. The approach should provide one viewpoint for decision making and support multiple criterion decision problems. In order to make informed and reliable decisions, the approach should provide correct and certain outputs. Hence, we specify the following set of success criteria with respect to the approach to visualizing the decision alternatives:

Success criterion 7 - *The approach to visualizing the decision alternatives provides one viewpoint for decision making.*
The approach to visualizing the decision alternatives should be able to graphically visualize the overall performance of the decision alternatives with respect to the selection criteria involved. The approach should facilitate multiple criterion decision problems and provide one viewpoint for decision making. The decision maker should not have to relate to multiple models in order to make an informed decision.

Success criterion 8 - *The approach to visualizing the decision alternatives is sufficiently comprehensible.*
The approach to visualizing the decision alternatives should be sufficiently comprehensible and easy to understand by the decision maker. The decision maker should be able to understand the model correctly and be able to distinguish the decision alternatives involved. Hence, the decision maker should be able to make an informed

decision based on the information and data provided by the model. Indicators for this include ability to use the model correctly and correct interpretation.

Success criterion 9 - *The approach to visualizing the decision alternatives is sufficiently correct and certain.*

This implies that the outputs from the approach are unbiased as well as sufficiently accurate and precise for the purpose intended, and should substantiate and support the decisions made by the decision maker. In that manner, uncertainties must be taken into account. The uncertainties involved must be reported and managed properly.

Chapter 3

Research method

In this chapter we present the research method applied in the research of this thesis. Section 3.1 presents a method for technology research, followed by a presentation of evaluation strategies in Section 3.2. We briefly discuss research methods that we found appropriate for conducting our research in Section 3.3. In section 3.4 we describe our application of the research method.

3.1 Method for technology research

In order to accomplish our objective, we need to evaluate the set of success criteria discussed in the previous chapter. Evaluation is often based on hypotheses and predictions. During the evaluation phase a hypothesis often will either be confirmed or rejected. However, it is important to note that a confirmed hypothesis might not be true. Such hypotheses-testing is widely used in both classical and technology research [8]. The hypothesis of technology research is concerned with the artifact fulfilling and satisfying the set of success criteria [8]. According to Solheim and Stølen [8], there are some differences in evaluation within classical and technology research: classical research is often based on the need of a new theory, while technology research on the other hand is concerned with the need of a new artifact or improve an existing artifact. "The artifact should represent new knowledge, the new knowledge should be of interest to others, and the results and the new knowledge should be documented in a way that enables re-examination" [8]. However, Solheim and Stølen claim that both classical and technology research are based on an iterative process consisting of problem analysis, innovation, and evaluation as illustrated by Figure 3.1 [8].

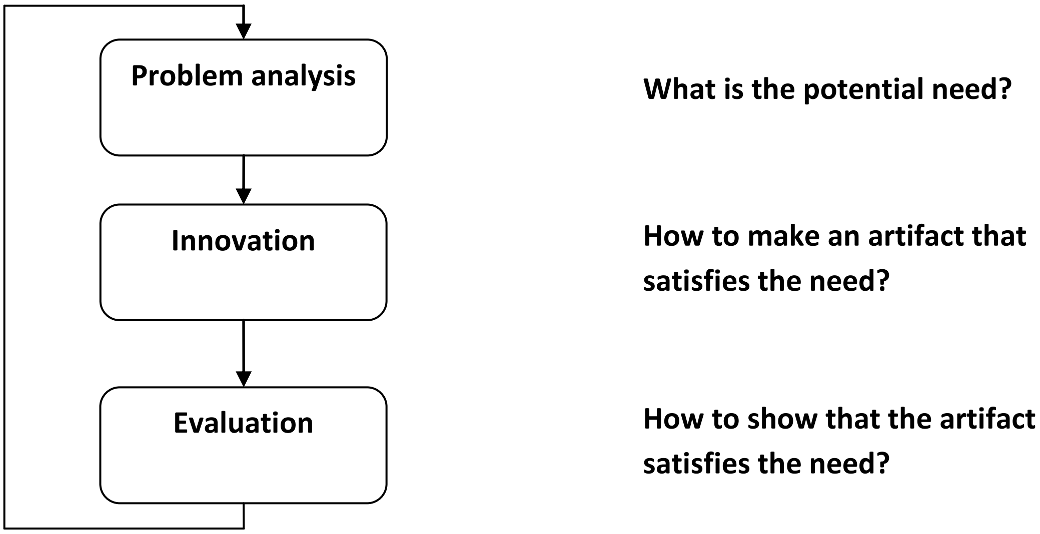

Figure 3.1: Method for technology research (adopted from Solheim and Stølen [8])

The artifacts and the related needs and requirements should be identified during the problem analysis phase. The innovation phase consists of designing a solution based on the identified needs (artifacts). Further, we need to evaluate our artifacts in the evaluation phase.

3.2 Evaluation strategies

A research method consists of a strategy for evaluation. There exists a range of research methods that are widely used within both classical and technology research. Every research method has some strengths and weaknesses, which have to be considered when selecting an appropriate research method. When selecting research method, it is important to take into account the resource constraints associated with the research. According to McGrath [9], there are mainly three desired properties or factors that should be maximized:

Generality This implies the generalization of results across populations. Various research methods can provide different degree of generalization from a much smaller sample [9].

Precision This implies the degree of preciseness in measurements. Accuracy and preciseness in measurements is important to obtain sufficient results [9].

Realism This implies the degree of realistic situation or context. A research conducted in a realistic situation is believed to have more accurate results.

A research method that fulfills all three properties would obviously be the optimal choice. However, as illustrated by Figure 3.2, it is impossible to maximize all three properties by only employing one research method. It is therefore important to apply multiple research methods that complement each other. As McGrath [9] rightly states: "Using multiple research methods might add strength to the resulting evidence by offsetting each other's weaknesses".

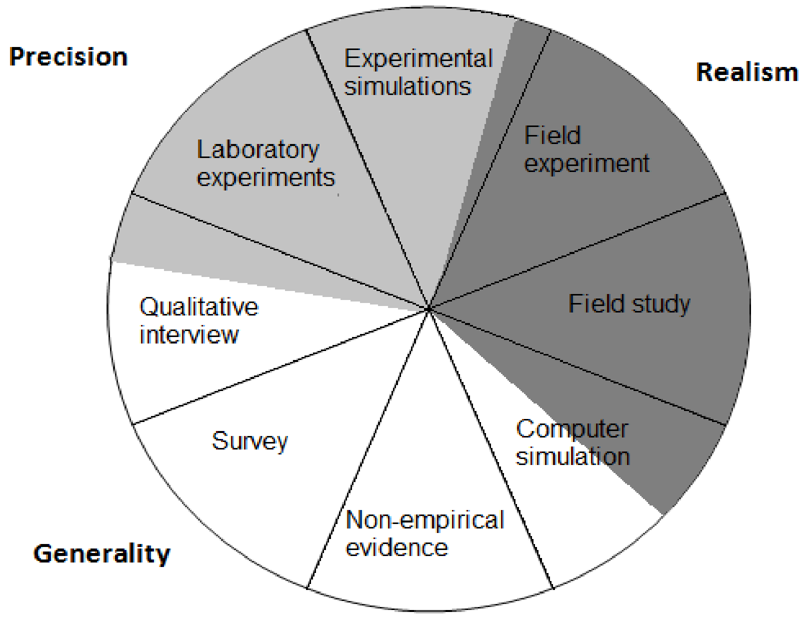

Figure 3.2: Research strategies (adopted from Solheim and Stølen [8])

3.3 Select the appropriate research method

Drawing on the challenges in the previous sections, we here briefly discuss research methods that we find appropriate for conducting our research.

A *case study* [10] [11] involves an in-depth examination of a single instance – a case. A case study is an empirical inquiry that investigates an instance or event within its real-life context [10]. "Case studies are by definition conducted in real world settings, and thus have a high degree of realism, mostly at the expense of the level of control" [12]. According to Runeson and Höst [12], the key characteristics of a case study are that (1) it is flexible, coping with the complex and dynamic aspects of real world phenomena, (2) its conclusions are based on a clear chain of evidence, collected from multiple sources in a planned and consistent manner, and (3) it adds to existing knowledge.

Thought experiment concerns solving theoretical problems by using the human imagination [13]. As pointed out by Brown [13]: “Thought experiments are performed in the laboratory of the mind”. A thought experiment is often based on a hypothesis, theory, or principle [13]. Thought experiments are often conducted to explore complex subjects that cannot be empirically tested or observed, “either because we lack the relevant technology or because they are simply impossible in principle” [13]. Thought experiment assumes that the participants involved are qualified, have a high level of expertise, and are able to simulate the reality in question.

Action research [14] is often considered a combination of a field experiment and a case study, where the researcher is actively participating in the research. According to Solheim and Stølen [8]: “Action research is described as research and/or development directed towards the improvement of processes or systems within organizations. The goal is to reduce or eliminate organizational problems by improving the organization. The action researcher brings change into the organization by intervening it and then observing the effects of the changes”. The researcher enters a real-life situation and aims to improve it, gain a deeper understanding of it, and to attain knowledge [14]. The cooperative collaboration between the researcher and the participants is often considered as the uniqueness of action research [14].

Considering the nature of our research, we find the combination of case study and thought experiment appropriate for conducting our research. The combination of case study and thought experiment fulfills our needs and requirements. In addition, both case study and thought experiment is possible to conduct with respect to the time and resource constraints associated with our research.

3.4 Our application of the research method

Our research method has been carried out in the context of a technology research method. Prior to our research, we developed an initial design of our decision making method based on a general problem description. The initial design was then conducted and performed through a case study with close collaboration with the domain experts. The case study was based on the guidelines for a case study research proposed by Yin [11] and Runeson and Höst [12]. Case study research provides the opportunity to explore ideas and innovative solutions in real-life settings. We were thus able to investigate the performance of the initial design of our proposed decision making method in a realistic setting. Figure 3.3 illustrates the iterative process that was undergone during the development of the artifacts.

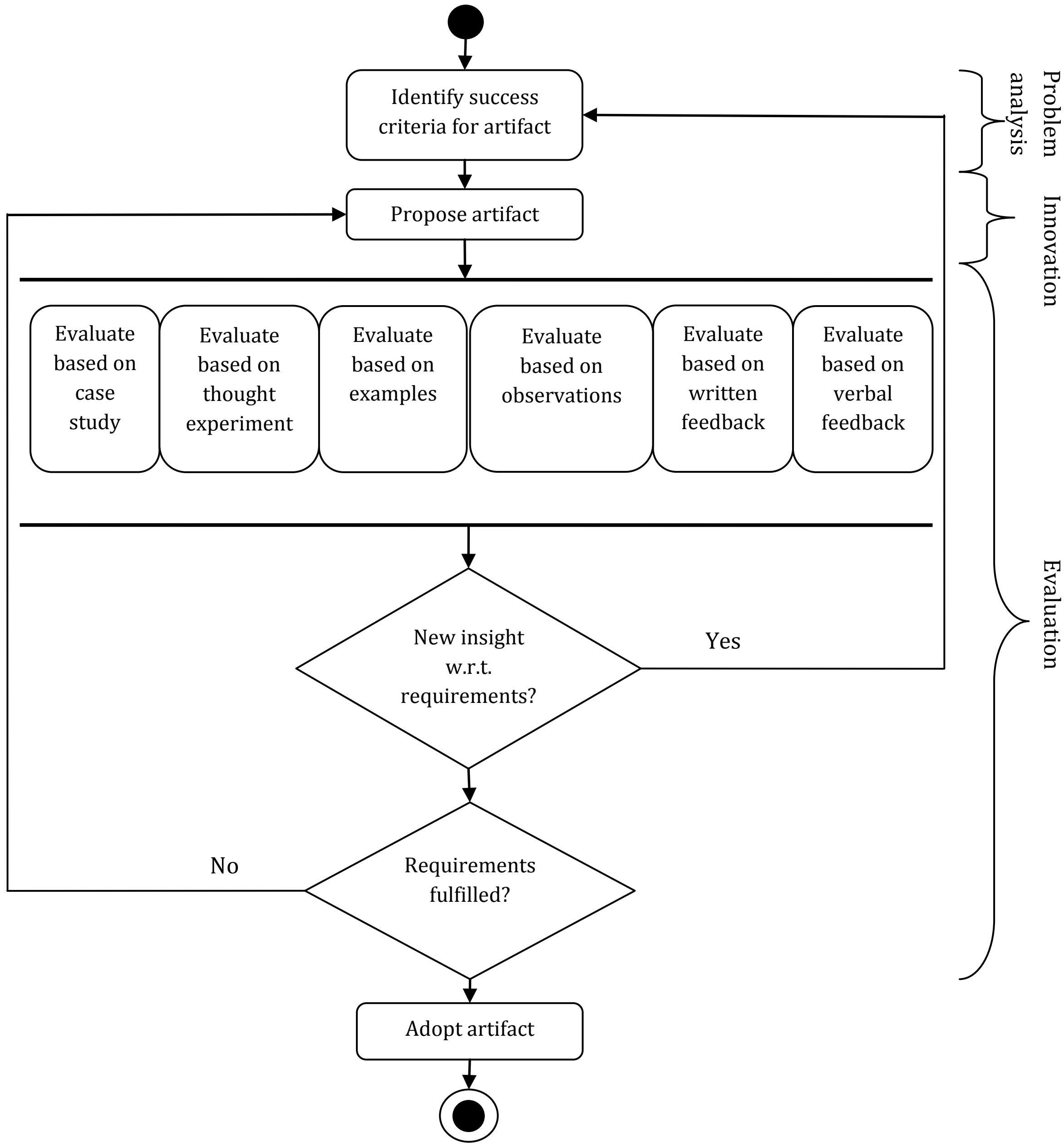

Figure 3.3: Iterative research method (adopted and modified from Refsdal [15])

The process of the decision making method was evaluated based on the case study, through thought experiment, written feedback after the analysis, and observations from the case study. The approach to modeling in the decision making method was partially evaluated based on the case study, through thought experiment, written feedback after the analysis, and observations from the case study.

However, the evaluation from the case study triggered a need to express the functional fulfillments associated with the decision alternatives. The needs and requirements related to the functional fulfillment analysis were specified during the case study in close collaboration with the domain experts. The functional fulfillment analysis was mainly evaluated by applying examples from the case study.

The approach to visualizing the decision alternatives was evaluated mainly by applying examples from the case study and verbal feedback collected after the example-based demo. In the following sections we present in more detail the development and evaluation of the artifacts.

3.4.1 The process of the decision making method

The evaluation of the process of the decision making method was mainly based on a case study. The objective of the case study was to investigate the performance and the practical feasibility of the process in a realistic context. All the phases of the process of the decision making method were conducted during the case study. The overall outline for the research method is illustrated by Figure 3.4.

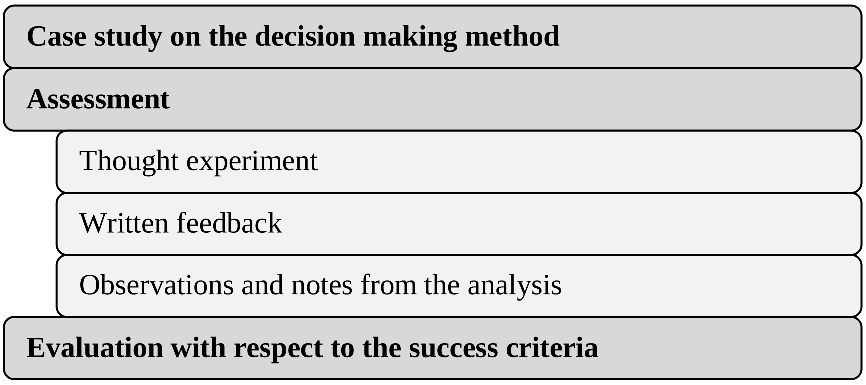

Figure 3.4: Outline for the research method

As depicted by Figure 3.4, the evaluation of the initial design was based on a thought experiment, followed by a written feedback from the domain experts after the analysis. The objective of the thought experiment was to evaluate and verify the estimates provided by the domain experts. Additionally, observations and notes were made during the analysis of the process. Furthermore, the initial design of the process was evaluated with respect to a pre-defined set of success criteria.

The application of the initial design of the process on a real-life case provided useful insights into strengths and weaknesses of the process and suggested directions for improvements. The problem description was initially underspecified, but during the case study it was refined and specified into a set of success criteria with respect to the artifacts. The set of success criteria for the process of the decision making method is presented in Chapter 2.

3.4.2 The approach to modeling in the decision making method

Similarly to the process of the decision making method, the evaluation of the approach to modeling in the decision making method was partially based on the same case study. During the evaluation of the approach to modeling in the decision making method we primarily focused on the comprehensibility, correctness, and expressiveness of the models.

It is important to emphasize that even though these artifacts are treated separately throughout this thesis; they were in fact developed and partially evaluated in parallel. The initial design of the approach to modeling in the decision making method was evaluated based on a thought experiment, followed by a written feedback from the domain experts after the analysis. Observations and notes were made during the analysis of the approach.

The evaluation of the approach to modeling in the decision making method indicated a need to express the functional fulfillments associated with the decision alternatives. The approach was further improved and extended based on the needs and requirements identified during the case study. The approach to modeling in the decision making method was extended by employing functional fulfillment analysis.

The extended feature of functional fulfillment analysis was developed in close collaboration with the domain experts during two workshops with duration of four hours in total. The domain experts were involved in defining and specifying the needs and requirements related to the approach. Based on the target system description and the UML system models [16] from the case study, the analyst was to a certain degree able to propose an initial design of the feature. The development and improvement of the artifact was based on the process described by Figure 3.3. The functional fulfillment analysis was mainly evaluated by applying examples from the case study. Finally, the approach to modeling in the decision making method was evaluated with respect to a pre-defined set of success criteria. The set of success criteria for the approach to modeling in the decision making method is presented in Chapter 2.

3.4.3 The approach to visualizing the decision alternatives

The approach to visualizing the decision alternatives was iteratively developed and evaluated in close collaboration with the domain experts as depicted by Figure 3.3. The evaluation of the approach was mainly based on exemplifications. The approach to visualizing the decision alternatives was applied on examples from the case study and the results obtained were evaluated accordingly. The needs and requirements of the approach were identified during the case study and refined into a set of success criteria. The domain experts provided useful feedback during the development of the approach. Observations and notes were made during the development and evaluation of the approach. Finally, the proposed approach to visualizing the decision alternatives was evaluated with respect to the pre-defined set of success criteria. The set of success criteria for the approach to visualizing the decision alternatives is presented in Chapter 2.

Chapter 4

State of the art

In this chapter we present the related state of the art for this thesis with respect to our three artifacts: the process of the decision making method, the approach to modeling in the decision making method, and the approach to visualizing the decision alternatives.

4.1 The process of the decision making method

In this section we briefly present the state of the art related to the process of the decision making method. The process of the decision making method ensures the integration of cost, risk, and quality aspects. Therefore, we here present various concepts and methods for cost, risk, and quality estimation. We first highlight some important concepts within investment of Information Technology and benefit-cost analysis. Moreover, a brief presentation of various approaches to cost estimation and models of cost estimation are given. We then briefly highlight some key indicators of cost, risk, and quality. In the end, methods for quality and risk analysis are presented.

4.1.1 Investment in Information Technology

There has been an increasing focus on the investment in Information Technology [17]. The deployment of Information Technology has not always proved to be beneficial for the enterprise [17]. The management of organizations and enterprises often look at financial aspects in important decision making situations. As pointed out by Gunasekaran et al. [17]: "Well-managed IT investments that are carefully selected and focused on meeting business/mission needs can have a positive impact on an organisation's performance. Likewise, poor investments, those that are inadequately justified or whose costs, risks, and benefits are poorly managed, can hinder and even restrict the organisation's performance". Common reasons are that "executives are often unsure about how IT may be effectively implemented and most view IT from a technical rather than a business approach" [17]. A popular trend is to apply methods and concepts from Economics and Business Administration to the field of Information Technology [17]. Several concepts have been designed to evaluate the investments in Information Technology. Return on Investment (ROI) is probably the most well-known concept to evaluate IT investments [17]. Return on Security Investment (ROSI) is derived from ROI to evaluate investments in Information Security. Gunasekaran et al. [17] present a model to determine and justify IT investments.

Likewise, Faisst et al. [18] present a mathematical concept to determine investments in Information Security. The idea of Net Present Value (NPV) is derived from the concept of ROSI [18]. The NPV-formula is a mathematical calculation for Information Security investments [18]:

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{\Delta E(L_t) + \Delta OCC_t - C_t}{(1 + i_{calc})^t}$$

$$I_0 = initial\ investment\ for\ security\ measure$$

$$\Delta E(L_t) = reduction\ in\ expected\ loss\ in\ t$$

$$\Delta OCC_t = reduction\ in\ opportunity\ costs\ in\ t$$

$$C_t = cost\ of\ security\ measure\ in\ t$$

$$i_{calc} = discount\ rate$$

The NPV-formula gives an output of either a positive or negative value. Based on the output value an enterprise might decide to make an Information Security investment or not.

4.1.2 Benefit-cost analysis

Benefit-cost analysis or cost-benefit analysis (CBA) is a "decision-making tool used to systematically develop useful information about the desirable and undesirable effects of projects" [19]. According to Park [19]: "Comparison of the investment costs of a project with the project's potential benefits, a process known as benefit-cost analysis, is an important feature of the economic analysis method". In that manner, a cost-benefit analysis is an economic analysis technique for evaluating the economic profitability of a project or system.

Cost-benefit analysis is a method for identifying and highlighting the consequences of actions before decisions are made [19]. Using such a systematic approach makes it easier to compare the effects of various actions and alternatives. A cost-benefit analysis makes a comparison of the potential benefits and the investment costs related to a project or system. Considering Information Technology, cost-benefit analysis is a relatively simple and widely used technique for deciding whether to adopt an IT solution or not. Cost-benefit analysis is widely used in various domains to compare alternatives and thus choose the most beneficial one [19]. While cost estimation has improved over time in other domains, Information Technology has faced serious challenges regarding estimation and prediction of costs [19].

Research shows that approximately 30% of IT-projects tend to run over estimated costs [20]. The study from the University of Oxford's Said Business School [20] states that costs overrun in big IT-projects leads to one in three failures. Continuous changes in technology are probably one of the main reasons for costs overrun in IT-projects. A cost overrun is an unexpected exceed in estimated and predicted costs [21]. Cost overrun is often calculated either as (1) a percentage; actual cost minus estimated cost in percent of estimated cost, or as (2) a ratio; actual cost divided by estimated cost [21]. "If underestimation were unintentional and related to lack of experience or faulty methods in estimating and forecasting costs, then, a priori, we would expect underestimation to decrease over time as better methods were developed and more experience gained" [22].

A sad fact is that there has not been any improvement in cost estimation in Information Technology. The ticket system for public transport in Oslo and Akershus – Flexus (now called Elektronisk Reisekort) – was believed to have exceeded more than 200 million NOK [23]. The project itself evolved to become one of the biggest public scandals in Norway in recent time, and received strong criticism. This is only one of many examples regarding cost overruns in IT-projects in Norway. As Hashimoto and Hruska [24] rightly state: "Inaccurate costs estimations can cause severe financial burden for an enterprise if accurate CBA is not carried out appropriate".

“When software engineers and project managers talk of cost estimation, they usually mean predictions of the likely amount of effort, time, and staffing levels required to build a software system. Because staff costs often dominate overall project cost, the terms cost estimation and effort estimation are sometimes used interchangeably” [25]. Cost estimates are often performed throughout the life cycle of an IT-project or software development. Initial cost estimates are typically necessary to evaluate the IT-project and its profitability. Cost estimates later in the project are required by the management to monitor continuous improvement. Moreover, as Figure 4.1 illustrates, cost estimates later in the project tend to be more accurate, since the level of uncertainty declines as the project progresses.

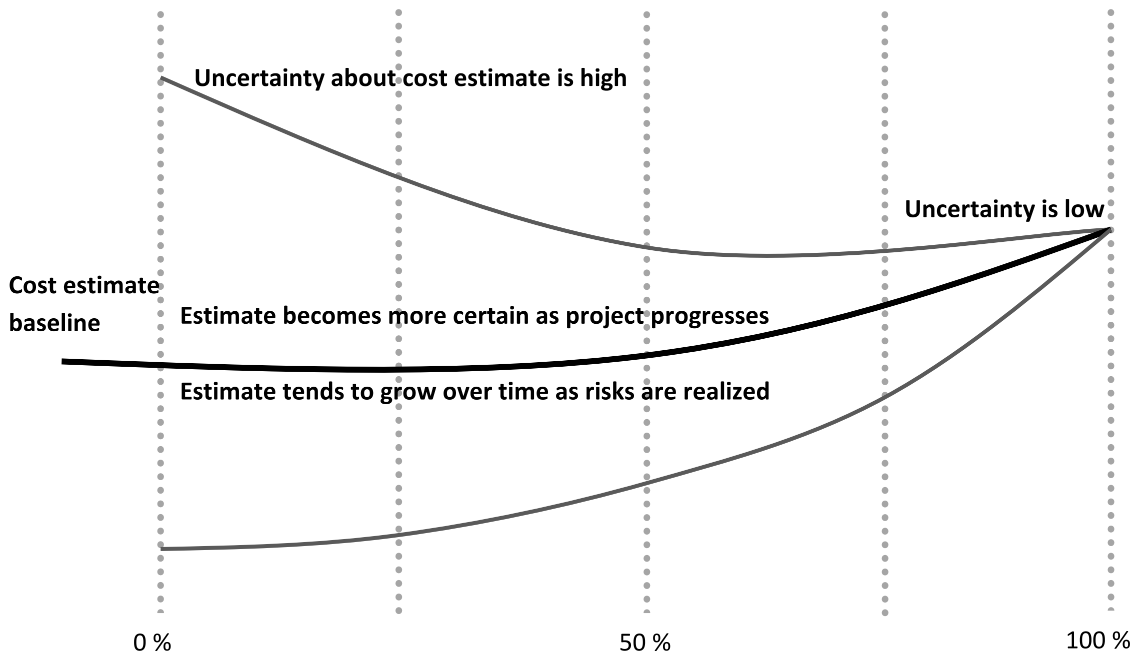

Figure 4.1: Uncertainty of cost estimates (adopted from GAO [26])

4.1.3 The approaches to cost estimation

There are several techniques for cost estimation. Software engineers tend to use mainly five techniques [25] [27]:

Expert judgement This technique is mainly based on opinions given by experienced experts. The experts might use tools and models to produce cost estimations. The quality of the cost estimations rely heavily on the experts and their breadth of

	experience. According to Sommerville [27]: "They each estimate the project cost. These estimates are compared and discussed. The estimation process iterates until an agreed estimate is reached".
Estimation by analogy	This technique is mainly based on comparisons to previous completed projects in the same domain [27]. The estimators identify common similarities and differences between the initial project and past projects. The estimates are typically adjusted according to the differences.
Decomposition	This technique is mainly based on decomposing the initial project into smaller components [27]. Cost estimates are then generated based on these components. This technique usually takes advantage of a Work Breakdown Structure (WBS) [27]. The cost estimates of the various components are then combined to produce an overall estimate of the initial project.
Models	Several models have been developed to generate accurate cost estimates. These models often require some kind of input variables. Cost estimates are then generated based on these input variables. We present some common used models of cost estimation in Section 4.1.4.
Pricing to win	The cost estimation is strongly influenced by the customer's affordability [27]. According to Sommerville [27]: "The estimated effort depends on the customer's budget and not on the software functionality". This technique is commonly used for creating winning project bids.

4.1.4 Models of cost estimation

The Constructive Cost Model (COCOMO) [25] invented by Boehm in the 1970's is one of the most well known cost models for cost estimation in Information Technology and software engineering. The model predicts costs, effort, and schedule for a given project based on cost drivers [25]. Cost drivers are variables that might have an effect on the estimation of the overall system, such as size, line of codes (LOC), and developers' level of experience etc. "Lines of source code per programmer-month (LOC/pm) is a widely used software productivity metric" [27]. Due to consistent changes in technology, a revised version of the model was later developed and launched as COCOMO 2.0 [25]. Another well known model of cost estimation is the SLIM model by Putnam [25]. A common factor for these models is that they are both based on top-down estimation [25]. Hence, they predict the cost of the overall system or project.

4.1.5 Cost, risk, and quality indicators

We often use indicators to assign and quantify conditions that are too complex or expensive to measure directly [28]. An indicator is often defined as "something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable" [28]. In that manner, indicators are generally statements or formulas specifying how to obtain a value of interest. We daily encounter traditional indicators, for example the price index or the life expectancy.

There are several approaches and frameworks providing indicators for measuring cost, risk, and quality within the field of Information Technology. The International Organization for Standardization has developed and published international standards for quality and risk management. ISO/IEC 9126 [29] is probably the most well known international standard for the evaluation of software quality. It provides well defined indicators and metrics for quality measurements. "ISO/IEC 27004 provides guidance on the development and use of measures and measurement for the assessment of the effectiveness of an implemented information security management system (ISMS) and controls, as specified in ISO 27001" [30]. The Performance Measurement Guide for Information Security published by the National Institute of Standards and Technology

(NIST) [31] provides assistance on the selection of suitable indicators and metrics for information security measurements.

4.1.6 Methods for quality and risk analysis

CORAS [7] is a model-driven approach to risk analysis, and is strongly related to international standards on risk management, such as ISO 31000. The CORAS approach aims to focus on precise and efficient model-based risk analysis of information systems [7]. Other alternative risk analysis approaches, such as CRAMM [32] and OCTAVE [33] rely heavily on text and tables. On another side, the CORAS approach uses diagrams as an important means for communication, evaluation, and assessment [7]. Model-based risk analysis provides several graph-based and tree-based notations, such as Event Tree Analysis (ETA) [34] and Fault Tree Analysis (FTA) [35].

According to Lund et al. [7]: "The comprehensiveness of CORAS is manifested by the three complimentary parts of the approach. CORAS consists of a customized language for risk modelling, a tool supporting the language, and a risk analysis method into which the tool-supported risk modelling language is tightly interwoven. It is particularly the specialized support for risk modelling that distinguishes CORAS from other approaches to risk analysis". The CORAS risk analysis is mainly performed in eight steps [7]: (1) Preparations for the analysis, (2) Customer presentation of the target, (3) Refining the target description using asset diagrams, (4) Approval of the target description, (5) Risk identification using threat diagrams, (6) Risk estimation using threat diagrams, (7) Risk evaluation using risk diagrams, and (8) Risk treatment using treatment diagrams.

PREDIQT [36] is a method for model-based prediction of impacts of architectural design changes on system quality. The main objective of a PREDIQT-based quality analysis is prediction of information system quality by identifying various quality aspects, evaluating each of these, and composing the results into an overall quality evaluation [36]. According to Omerovic [36]: "The intended benefits of PREDIQT include improved understanding of the system design and the alternatives for potential improvements, as well as existing and potential weaknesses of architectural design, with respect to individual quality characteristics and their trade-offs".

4.2 The approach to modeling in the decision making method

In this section we briefly present the state of the art related to the approach to modeling in the decision making method. We first highlight some important concepts within modeling approaches in general. The approach to modeling in the decision making method should be able to address overlap between the decision alternatives. In that manner, we also present some relevant traceability approaches. Finally, we present the notion of feature modeling.

4.2.1 Modeling approaches

Weighted Dependency Trees (WDTs) [37] are used in multiple range of domains. Important decisions regarding system analysis are usually based on WDT analysis [37]. A common type of WDT is decision trees. Decision trees graphically depict the sequence of possible actions and outcomes by a combination of lines and nodes [1]. According to Ravindran [1]: “There are two types of nodes used in a decision tree. A square represents a decision point or fork, which is the action (alternative) taken by the decision maker and a circle represents an event or chance fork, which is the state of nature”. The branches between the nodes represent the decision path decided by the decision maker [1]. Decision trees are widely used as a decision support tool in various domains. Examples of widely used decision trees include Fault Tree Analysis (FTA) [35], Event Tree Analysis (ETA) [34], and attack trees [38].

Fuzzy logic is a generic term for several decision making models based on the fuzzy set theory. The fuzzy set theory was introduced in 1965 by L. A. Zadeh [39]. O’Hagan [40] presents a fuzzy decision making model developed by L. A. Zadeh and Richard Bellman which has proved to be useful to decision makers in many real-life problems. According to O’Hagan [40]: “One of the most useful aspects of fuzzy set theory is its ability to represent mathematically a class of decision problems called multiple objective decisions (MODs). This class of problems often involves many vague and ambiguous (and thus fuzzy) goals and constraints. The object of the fuzzy decision methodology is to obtain a decision, optimum in the sense that some set of goals is attained while observing (i.e. not violating) a simultaneous set of constraints”.

Bayesian Belief Networks (BBNs or Bayes nets for short) belong to the family of probabilistic graphical models (GMs) [41]. "In particular, each node in the graph represent a random variable, while the edges between the nodes represent probabilistic dependencies among the corresponding random variables" [41]. BBNs combine principles from computer science, graph theory, probability theory, and statistics [41]. BBNs correspond to another GM structure known as a directed acyclic graph (DAG). Any DAG can be represented as a WDT by duplicating the nodes [37]. According to Ben-Gal [41]: "BNs are both mathematically rigorous and intuitively understandable. They enable an effective representation and computation of the joint probability distribution (JPD) over a set of random variables". Similar to decision trees, BBNs are widely used as a modeling approach in various domains.

4.2.2 Process modeling

There are several languages and notations for process modeling. Business Process Model and Notation (BPMN) [42] and Unified Modeling Language (UML) [43] are certainly the most well known graphical notations. BPMN and UML are used to create visual and graphical representations of information systems. According to the Object Management Group [42]: "A standard Business Process Modeling Notation (BPMN) will provide businesses with the capability of understanding their internal business procedures in a graphical notation and will give organizations the ability to communicate these procedures in a standard manner". Both BPMN and UML are widely used to visualize information systems. UML includes a range of diagrams to construct, visualize, and represent various elements in an information system [43]. The main purpose of such modeling approach is to better understand the overall information systems and its various components. In that manner, such modeling approach creates high-level representations of the target system.

4.2.3 Traceability approaches

Traceability is defined as "the ability to establish degrees of relationship between two or more products of a development process, especially products having a predecessor-successor or master-subordinate relationship to one another" [44]. Traceability approaches help to identify the origin of an artifact and the relationship between various artifacts. Galvão and Goknil [45] present various traceability approaches based on cross-references, graph-based representations, and matrices.

According to Aizenbud-Reshaf et al. [46], the first method to express and maintain traceability was cross-referencing. Cross-referencing allows linkage between an entity to another entity elsewhere in the same project documentation. The manual specification and maintenance of cross-references is a major constrain [46]. However, several tools have been developed in order to support automated cross-referencing, such as hypertext links [46].

A traceability approach aimed at simplifying the management of relationships between project requirements and various design artifacts is presented by Galvão and Goknil [45]. "The methodological framework proposed facilitates tracing of requirements, assessing the quality of model transformation specifications, meta-models, models, and realizations" [45]. The framework suggests use of cross-tables to represent and visualize the traces [45].

Galvão and Goknil [45] outline another requirements-driven traceability approach known as Event Based Traceability (EBT). EBT aims to facilitate automation of trace-link generation and maintenance. According to Galvão and Goknil [45]: "Instead of establishing direct and tight coupled links between requirements and dependent entities, links are established through an event service. First, all artifacts are registered to the event server by their subscriber manager. The requirements manager uses its event recognition algorithm to handle the updates in the requirements document and to publish these changes as event to the event server. The event server manages some links between the requirement and its dependent artifacts by using some information retrieval algorithms". Moreover, a Goal Centric Traceability (GCT) approach aims to manage the impact of change associated with the non-functional requirements of a software system [45].

4.2.4 Feature modeling

A feature diagram represents the features, characteristics, and aspects associated with the object in question [5]. Feature diagrams have a hierarchical tree structure containing either mandatory or optional features [5]. The various sub-features are often distinguished with or-, and-, or alternative-relationships [5].

Figure 4.2: Syntax of feature diagrams

Figure 4.2 illustrates the syntax of feature diagrams. Mandatory and optional features are described by the annotation illustrated in Figure 4.2 and represent an and-relationship. All mandatory sub-features must be selected in an and-relationship. The or-relationship describes features that are required by the parent-feature. In that manner, the sub-features of an or-relationship are indifferent and at least one sub-feature must be selected [5].

The alternative-relationship describes alternative features that are not required by the parent-feature, and exactly one sub-feature has to be selected [5]. It is important to mention that a feature that is not described in a feature diagram and specified by an alternative-relationship can still be selected as long it fulfills the purpose given by the parent-feature. We present the summarized definition of the alternative-, and-, and or-relationship:

Alternative-relationship:	Not required features and exactly one feature must be selected
And-relationship:	Mandatory and optional features
Or-relationship:	Required features and at least one feature must be selected

4.3 The approach to visualizing the decision alternatives

In this section we briefly present the state of the art related to concepts, methods, and various approaches for data visualization and decision making. Data visualization is a general term for understanding and presenting the significance of data by visual graphics [47]. Data visualization provides tools that are supposed to aid us in dealing with data complexity. According to Grinstein and Ward [47]: "Human beings look for structure, features, patterns, trends, anomalies, and relationships in data. Visualization supports this by presenting the data in various forms with differing interactions. A visualization can provide a qualitative overview of large and complex data sets, can summarize data, and can assist in identifying regions of interest and appropriate parameters for more focused quantitative analysis". Hence, data visualization concepts are widely used to explore and present data.

4.3.1 Data visualization techniques and concepts

Data visualization techniques and concepts can be classified in numerous ways, for instance based on the task at hand, based on the dimensions of display, or based on the structure of the underlying data set [47]. There are several important factors that must be considered when selecting an appropriate visualization. In the following we summarize the most common used data visualization techniques and concepts. Figure 4.3 illustrates some of the techniques and concepts mentioned below.

- ***Line charts****:* Line charts or graphs are the most widely used graph for showing trends (see Figure 4.3). "A line graph is formed by connecting points whose positions are determined by a variable (y dimension) for which you have values over a sequence of another variable (x dimension)" [47]. Line graphs are useful in displaying changes in data over intervals of time, but are insufficient for multiple criterion decision problems.
- ***Scatter plots:*** Scatter plots or scatter diagrams are very similar to line charts (see Figure 4.3). Unlike line charts, multiple data points can map to the same x or y coordinate [47]. In that manner, each point in a scatter plot is based on two dimensions or variables. However, scatter plots can depict three-dimensional data, where the third variable is portrayed by the plotted symbol [48].

- ***Bubble charts:*** Unlike scatterplots, bubble charts or symbolic scatter plots can display three to four dimensions of data [48]. In a bubble chart, the data points are replaced with bubbles; where the size and color of the bubble represent the third and the fourth dimension [48] (see Figure 4.3). Bubble charts are useful for displaying up to four dimensions of data.
- ***Bar charts:*** Bar charts or bar graphs display the distributions of categorical variables by using either horizontal or vertical bars [49] (see Figure 4.3). Bar charts are useful in comparing the size of different elements [49]. According to Moore and McCabe [49], bar charts are of limited use for data analysis because it is easy to understand data on a single categorical variable without a graph.
- ***Histograms:*** While bar charts compare the size of different elements, a histogram displays the distribution of counts or percents among the values of a single variable [49]. In a histogram, the range of values of the variable in question are grouped into selective classes [49]. The histogram then displays the count or percent of observations that are associated with the various classes [49]. According to Moore and McCabe [49]: "You should be aware that the appearance of a histogram can change when you change the classes".
- ***Pie charts:*** Pie charts are circular charts divided into categorical sectors, where each sector represents its proportional quantity [49] (see Figure 4.3). According to Moore and McCabe [49], you should only use pie charts when you want to emphasize each category's relation to the whole.
- ***Timeline charts:*** Timeline charts or time plots display the distribution of a variable in time order by having time on the horizontal scale and the measured variable on the vertical scale [49]. According to Moore and McCabe [49]: "Displays of the distribution of a variable that ignore time order, can be misleading when there is systematic change over time". Timeline charts help understanding any change in data over time.
- ***Radar charts:*** Radar charts or star plots display multivariate data in a star-shaped graph consisting of three or more quantitative variables [48] (see Figure 4.3). Each ray in the radar chart represents a variable.

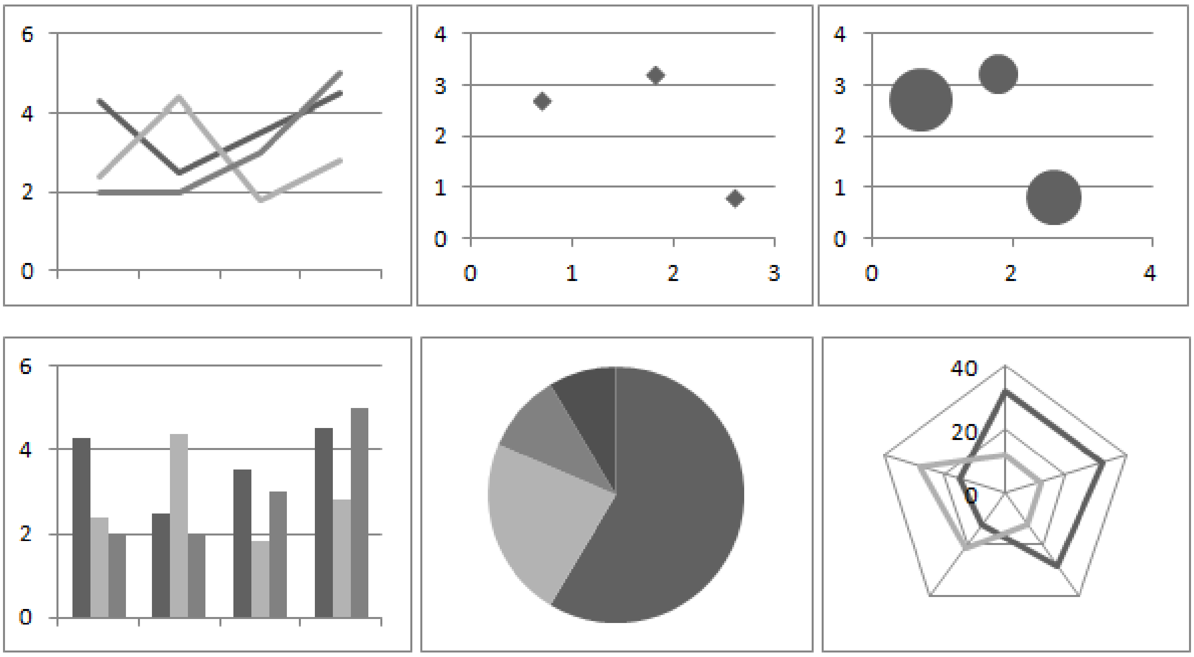

Figure 4.3: From upper left corner: line chart, scatter plot, bubble chart, bar chart, pie chart, and star plot

Chapter 5

An overview of the approach and its artifacts

In this chapter we provide an overview of the decision making method and its artifacts. We consider the artifacts to be the main building blocks of our proposed decision making method. Although we have treated the artifacts separately throughout this thesis, they are dependent on one another. The process of the decision making method employs the approach to modeling in the decision making method to facilitate the development of the models. The approach to visualizing the decision alternatives employs the approach to modeling in the decision making method to graphically represent and analyze the overall performance of the decision alternatives. The process of the decision making method ensures the integration of the approach to modeling in the decision making method and the approach to visualizing the decision alternatives. The artifacts and their overall relationship are depicted by Figure 5.1.

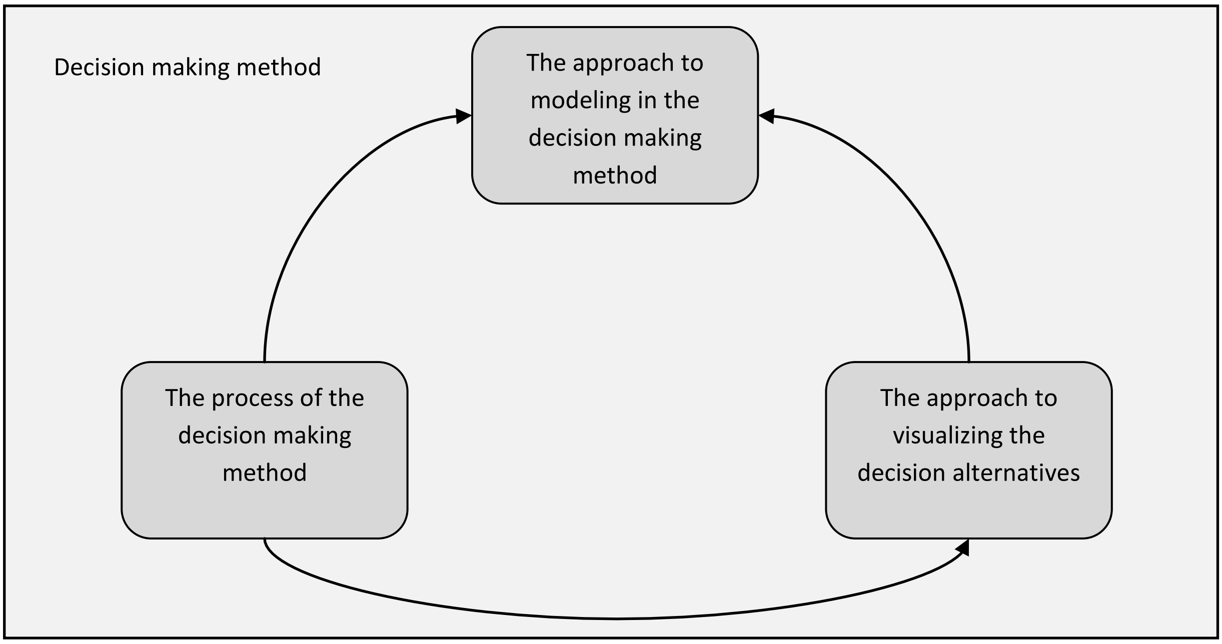

Figure 5.1: The artifacts and their relationship

5.1 The process of the decision making method

In this section, we present an overview of the process of the decision making method. The process of the decision making method aims to facilitate and guide the analyst to systematically conduct the decision making method. Figure 5.2 illustrates a general overview of the process of the decision making method and the various phases involved.

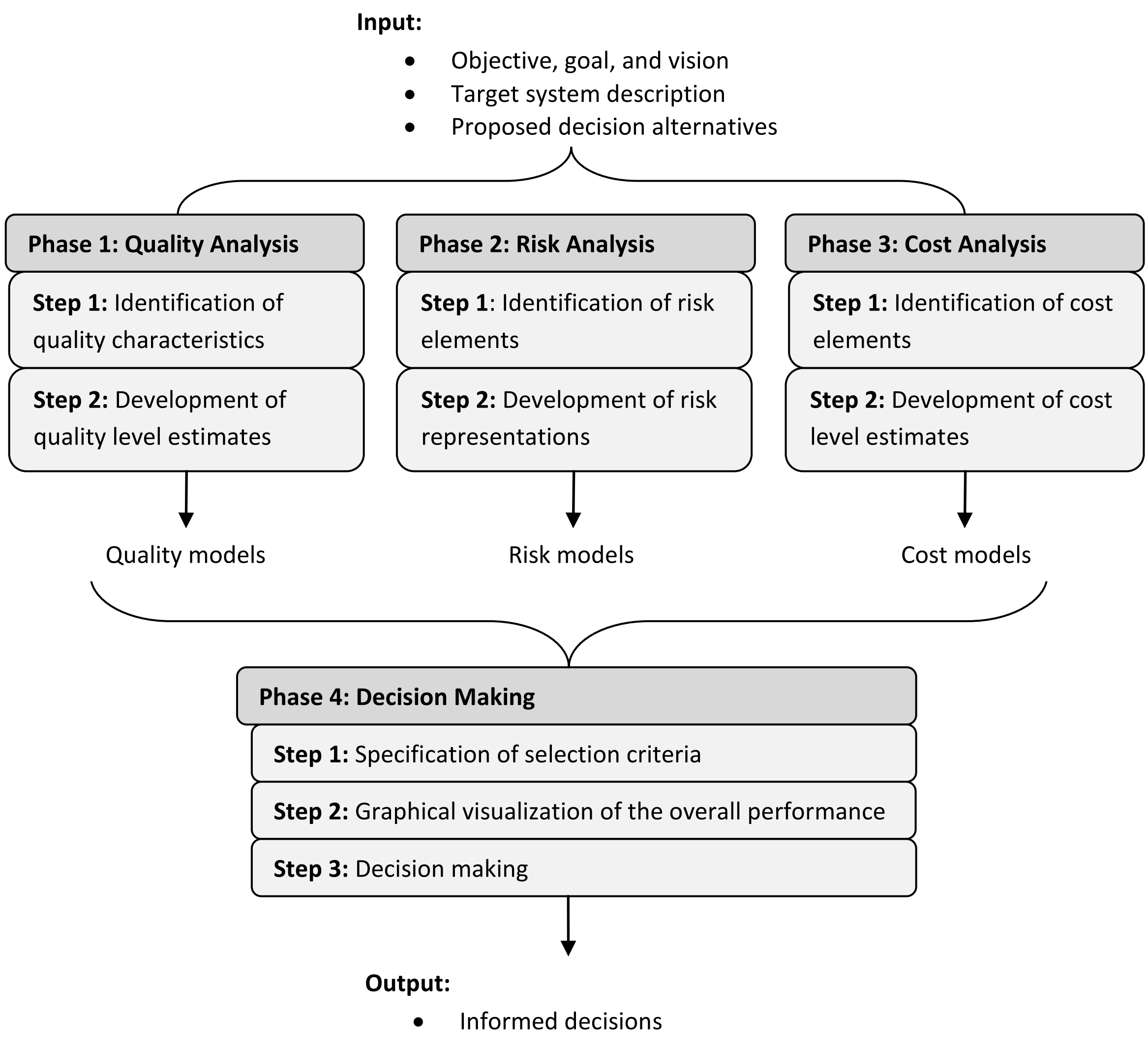

Figure 5.2: Overview of the process of the decision making

The process requires a specification of overall objective, goal, or vision; what does the enterprise want to achieve through the implementation of the proposed decision alternatives? The performance of the process should correlate with a preset goal or vision, which in turn should be visible throughout the decision alternatives. In that manner, the enterprise will beforehand have a set of selection criteria such as budget, quality etc. The proposed decision alternatives will thus meet the needs of the enterprise and comply with their overall objective, goal, or vision.

The process of the decision making method assumes that a target system description and specification of each of the decision alternatives are made in advance. The specification along with informed details about each alternative will be the input for the initial phases. A target system description is required and important to ensure common understanding between the stakeholders. Without a common understanding between the various stakeholders, we might encounter misinterpretations and misunderstandings regarding the target system under analysis in the phases ahead. The target system description should contain a detailed description of the system under analysis with informed system models (e.g., UML system models). Documents and specification of the target system under analysis and the proposed decision alternatives are important for the execution of the phases ahead. Table 5.1 describes the process of the decision making method in detail with important steps for each phase, relevant input and output for each phase, and the stakeholders involved.

Table 5.1: The process of the decision making method

		Input	**Output**	**Stakeholder**
 Step 1: Step 2:	**Phase 1: Quality Analysis** Identify quality characteristics for each of the proposed decision alternatives Development of quality level estimates	Documents and specification of the target system under analysis and the proposed decision alternatives	Quality level estimates	Analyst and domain experts
 Step 1: Step 2:	**Phase 2: Risk Analysis** Identify risk elements for each of the proposed decision alternatives Development of risk representations	Documents and specification of the target system under analysis and the proposed decision alternatives	Risk representations	Analyst and domain experts

Step 1: Step 2:	**Phase 3: Cost Analysis** Identify cost elements for each of the proposed decision alternatives Development of cost level estimates	Documents and specification of the target system under analysis and the proposed decision alternatives	Cost level estimates	Analyst and domain experts
Step 1: Step 2: Step 3:	**Phase 4: Decision Making** Specification of selection criteria Graphical visualization of the overall performance Decision making prior to deployment of the decision alternatives	Risk representation, quality and cost level estimates	Informed decisions	Analyst, domain experts, and decision maker

Each phase is denoted by a specific number. However, it is important to emphasize that this number does not necessarily reflect the sequence of the phases. Quality Analysis, Risk Analysis, and Cost Analysis are all independent of each other. In that manner, Quality Analysis, Risk Analysis, and Cost Analysis can be executed and conducted in any order. From our experience, these phases can be conducted in parallel as well. In the following we explain the various phases in detail:

Phase 1 – Quality Analysis – involves the development of quality level estimates associated with the decision alternatives. During the development of the target system description, the domain experts would have identified various quality characteristics associated with the target system under analysis. The objective of Quality Analysis is to provide sufficient quality level estimates associated with the identified characteristics. The domain experts in collaboration with the analyst are expected to provide necessary input to estimate the quality level of the various decision alternatives. The quality level estimates denote the impact on the quality characteristics after the implementation of the decision alternatives. Documents and specification of the target system under analysis and the proposed decision alternatives are necessary input for the execution of phase 1.

Phase 2 – Risk Analysis – involves the development of risk representations associated with the decision alternatives. During the Risk Analysis, the domain experts in collaboration with the analyst will identify various risks associated with the proposed decision alternatives. The domain experts are expected to provide necessary input regarding the consequence and likelihood of the risk in question. The consequence and the likelihood should be specified based on a specific scale. The objective of Risk Analysis is to provide sufficient risk representations. Documents and specification of the target system under analysis and the proposed decision alternatives are necessary input for the execution of phase 2.

Phase 3 – Cost Analysis – involves the development of cost level estimates of the information system after the implementation of the various decision alternatives. During the Cost Analysis, the domain experts are expected to provide necessary input to estimate the total cost of the various decision alternatives. The total cost denotes the total operational cost of the target system after the implementation of the decision alternatives. The objective of Cost Analysis is to provide sufficient cost level estimates. Documents and specification of the target system under analysis and the proposed decision alternatives are necessary input for the execution of phase 3.

Phase 4 – Decision Making – involves graphical visualization and analysis of the overall performance of the decision alternatives with respect to cost, risk, and quality aspects. In addition, the functional fulfillment analysis is conducted by the analyst in close collaboration with the domain experts. The degree of fulfillment achieved by the various decision alternatives is taken into account in the graphical visualization of the overall performance of the decision alternatives. By visualizing the decision alternatives in this manner, we aim to distinguish between the various alternatives based on their benefits and drawbacks with respect to the selection criteria. The outcome of this phase is a graphical visualization of the overall performance of the decision alternatives.

5.2 The approach to modeling in the decision making method

The approach to modeling in the decision making method aims to provide comprehensible support for the development of the models containing cost, risk, and quality-related information. The proposed decision making method offers notation, terminology, and guidance for developing these models. The approach makes use of existing modeling techniques and concepts. The utilized modeling techniques and concepts are well-known and are chosen with objective to be familiar to non-technical users. The approach to modeling in the decision making method is employed throughout the process of the decision making method. Figure 5.3 illustrates the elements of the approach to modeling in the decision making method, expressed as a UML class diagram. In the following we explain the approach to modeling in the decision making method in detail with respect to the various stages of the decision making process.

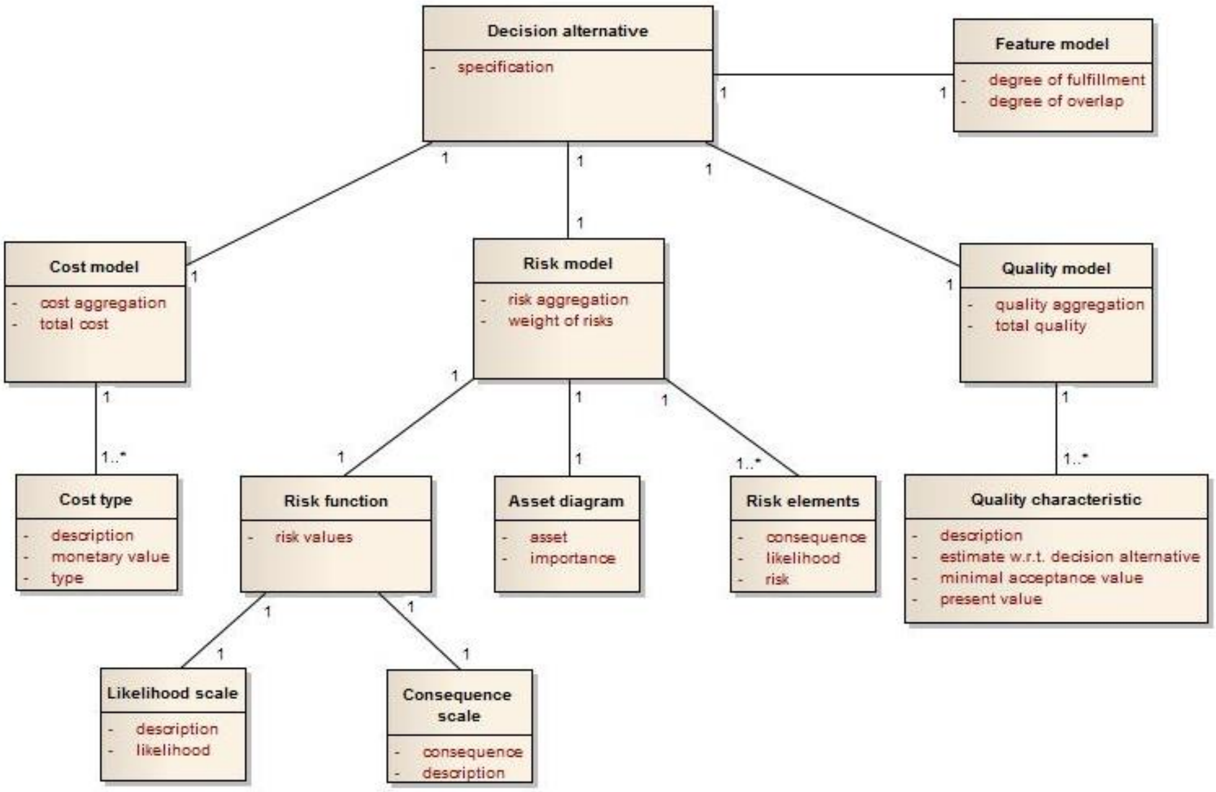

Figure 5.3: Elements of the approach to modeling in the decision making method

The approach to modeling in the decision making method supports the development of the cost level estimates during the Cost Analysis phase. The cost level estimates are represented by a cost model with the following parameters and properties: cost type, description of cost type, and the related monetary value. The monetary value reflects the operating cost of the target system with respect to the cost type in question. The cost model provides an aggregation function for generating the total cost associated with the decision alternative. The aggregation function should be based on empirical input, such as documentation, measurements, historical data, guidance, support, and expert judgements provided by the domain experts. The generated total cost reflects the total operating cost of the target system after the implementation of the decision alternative in question. The approach to modeling in the decision making method provides systematic structure and presentation of the overall performance of the decision alternatives with respect to cost aspects.

The approach to modeling in the decision making method supports the development of the quality level estimates during the Quality Analysis phase. During the Quality Analysis, the analyst will based on empirical input identify a set of quality characteristics associated with the target system under analysis. A present value and a minimal acceptance value should be identified with respect to the quality characteristics based on empirical input. The present value reflects the present performance of the target system with respect to the quality characteristics, while the minimal acceptance value denotes the minimal accepted performance. Considering the set of quality characteristics, the performance of the decision alternatives are expected to be estimated based on empirical input. Furthermore, the quality model provides an aggregation function for generating the total quality associated with the decision alternative. The specific aggregation function should be based on empirical input and should reflect the importance of the various quality characteristics. The total quality denotes the overall performance of the decision alternatives with respect to the quality aspects.

The approach to modeling in the decision making method supports the development of the risk models during the Risk Analysis phase. A risk model represents a risk function, an asset diagram, and risk elements. The Risk Analysis phase ensures identification and understanding of risk elements associated with the decision alternatives. A risk element represents a specific risk with assigned consequence and likelihood. The asset diagram includes possible assets that might be affected by the implementation of the various decision alternatives. Each asset is assigned an importance value based on a specific scale. The approach to modeling in the decision making method ensures the development of a consequence scale, likelihood scale, and a risk function for the assets identified. The risk function is expected to be assigned risk values based on empirical input. The risk values are specified in order to generate the total weight of risks for each decision alternative. The total weight of risks denotes the level of risks associated with the implementation of the various decision alternatives. The risk model provides an aggregation function for generating the weight of risks associated with the decision alternatives. The aggregation function should be based on empirical input.

The approach to modeling in the decision making method supports the development of a graphical representation of the overall performance of the decision alternatives during the Decision Making phase. The graphical representation provides comprehensible insight into the performance of the decision alternatives with respect to cost, risk, quality, and degree of fulfillment. The approach to modeling in the decision making method supports the calculation of the degree of fulfillment and the degree of overlap during the functional fulfillment analysis. In the following we explain the functional fulfillment analysis in more detail.

5.2.1 Functional fulfillment analysis

The approach to modeling in the decision making method provides a functional fulfillment analysis. By functional fulfillment analysis we mean the analysis of (1) degree of fulfillment of functional requirements with respect to the objective, and (2) degree of overlap between the decision alternatives with respect to the functional part of objective. The degree of fulfillment reflects the coverage of functional features related to the various decision alternatives with respect to the objective. By overlap we mean the association, interplay, and relationship between the various decision alternatives. The approach to modeling offers notation, terminology, and guidance for expressing the degree of fulfillment and the degree of overlap. Our proposed decision making method makes use of the notion of feature modeling [5] to express the degree of fulfillment and the degree of overlap. Feature diagrams are useful in the sense that they provide insight into the various features and functionalities implemented by the various decision alternatives. Section 4.2.4 provides more detailed information about feature diagrams and their syntax.

As depicted by Figure 5.3, our approach to modeling in the decision making method supports the development of feature diagrams representing the objective and the various decision alternatives. The feature diagram representing the objective reflects the ideal functionality of the target system under analysis. In that manner, the feature diagrams representing the various decision alternatives will be sub-graphs of the feature diagram representing the overall objective. The feature diagrams are expected to be developed by the analyst in close collaboration with the domain experts during the initial stages of the Decision Making phase. First of all, a feature diagram representing the ideal functionality of the target system should be developed. The feature diagram should contain features and mechanisms that fulfill the overall objective. Furthermore, feature diagrams representing the various decision alternatives should be developed. The feature diagrams enable the calculation of the degree of fulfillment and the degree of overlap achieved by the decision alternatives. In the following, we explain in detail the calculation behind the degree of fulfillment and the degree of overlap.

5.2.1.1 The degree of fulfillment

In this section, we present a mathematical formalization of the calculation behind the degree of fulfillment. The mathematical formalization of the calculation behind the degree of fulfillment follows a top-down approach. However, it is possible to conduct the degree of fulfillment based on a bottom-up approach. The calculation of the degree of fulfillment of a feature diagram is considered by comparing the nodes with an initial feature diagram representing the overall objective. A feature diagram is a set of nodes N, where each node n is assigned a weight w. A node denotes a relevant feature related to the decision alternative in question.

If n is a part of an and-relationship, then the assigned weight w of n should be taken into account by dividing w by the sum of weights assigned to all sibling nodes in the initial feature diagram. A node is a sibling to another node if they both share the same immediate parent node. In that manner, all sibling nodes are part of the same sub-graph.

Furthermore, we need to take into account the constraints provided by the alternative- and or-relationship. If the node in question is a part of an alternative- or or-relationship in the initial feature diagram, then we do not divide w by the sum of weights assigned to all sibling nodes. In that manner, we only consider the node in question and divide the weight w by itself. Furthermore, we do not distinguish between mandatory and optional nodes, since the difference between mandatory and optional features is already ensured and maintained through the assigned weights.

As an example, we let the initial feature diagram *FD* (corresponding to feature diagram representing the overall objective) contain the following nodes;

$$FD = \{n_i, \ldots, n_j\} \text{ where } i, j \in N$$

Similar, we let the feature diagram in question *FD'* (corresponding to feature diagram representing a decision alternative) contain the following nodes;

$$FD' = \{n_k, \ldots, n_z\}$$

In the following we summarize the general rules for calculating the degree of fulfillment:

- If n_i is a part of an and-relationship, then the calculated degree of fulfillment of the node in question will be $\frac{w_i}{w_{sum}}$, where w_{sum} denotes the total weight of all sibling nodes.
- If n_i is a part of an alternative- or or-relationship, then the calculated degree of fulfillment of the node in question will be $\frac{w_i}{w_i}$. In that manner, the degree of fulfillment achieved by a specific node in an alternative- or or-relationship will correspond to one.

When aggregating the total degree of fulfillment for the whole feature diagram, we provide the following pseudo code specified below. The pseudo code is based on a top-down approach.

1 Let *n* be the leftmost node in a feature diagram
2 If *n* is a part of an and-relationship then;
3 $\frac{w}{w_{sum}}$ where *w* denotes the weight of *n* and w_{sum} denotes the total weight of all sibling nodes
4 If *n* is a part of an alternative- or or-relationship then;
5 $\frac{w}{w}$ where *w* denotes the weight of *n*
6 Apply the above steps for every children node of *n*
7 The degree of fulfillment of *n* will be multiplied with the degree of fulfillment achieved by each children node
8 The degree of fulfillment achieved by the leaf-nodes taking part in an and-relationship will be summed

5.2.1.2 The degree of overlap

The degree of overlap explains to which extent two decision alternatives provide the same features and functionality. The degree of fulfillment tells nothing about the overlap between the decision alternatives. By overlap we mean the association, interplay, and relationship between the various decision alternatives. The degree of overlap follows the same mathematical calculation as the degree of fulfillment presented in the previous section. While the degree of fulfillment is calculated with the objective as reference model, the degree of overlap is obtained by having the various decision alternatives as reference models. The intuition of the degree of overlap is to identify decision alternatives with similar features and functionality. Our approach to modeling in the decision making method ensures that it is possible to explore overlap between decision alternatives by comparing the nodes in the feature diagrams. By integrating the degree of overlap with our decision making method, we can exclude a decision alternative that might provide the same features and functionality as another decision alternative.

5.3 The approach to visualizing the decision alternatives

The approach to visualizing the decision alternatives aims to provide comprehensible support for model-based selection of decision alternatives. Model-based selection involves selection of decision alternatives through visualization. The approach to visualizing the decision alternatives provides graphical representation of the overall performance of the decision alternatives with respect to the selection criteria. Our proposed approach makes use of star plots [48] to display the overall performance of the decision alternatives. Figure 5.4 illustrates a star plot displaying data in a star-shaped graph consisting of four selection criteria. Each ray in the star plot represents a selection criterion.

In our approach to visualizing the decision alternatives, the selection criteria are represented by total cost, weight of risks, total quality, and degree of fulfillment. The total cost, weight of risks, and total quality are obtained from the Cost Analysis phase, Risk Analysis phase, and the Quality Analysis phase as illustrated by Figure 5.2. The degree of fulfillment is obtained from the functional fulfillment analysis during the Decision Making phase. It is important to emphasize that the total quality reflects the non-functional requirements achieved by the decision alternatives, while the degree of fulfillment reflects the functional features related to the various decision alternatives.

According to example from Figure 5.4, decision alternative A performs better than B in terms of selection criteria 1, 2, and 3. Our approach to visualizing the decision alternatives supports the development of the star plot representing total cost, weight of risks, total quality, and degree of fulfillment.

The preferred decision alternative is determined based on the star with the largest area. It is important to emphasize that the selection criteria must be represented as benefit criteria. Total quality and degree of fulfillment are both benefit criteria in which more is better, while total cost and weight of risks are cost criteria in which less is better. Our approach addresses this issue by transforming the total cost and weight of risks to equivalent benefit criteria by taking the inverse of them. In that manner, a decision alternative that fulfills the maximum level of total cost, weight of risks, total quality, and degree of fulfillment defines the preferred decision alternative.

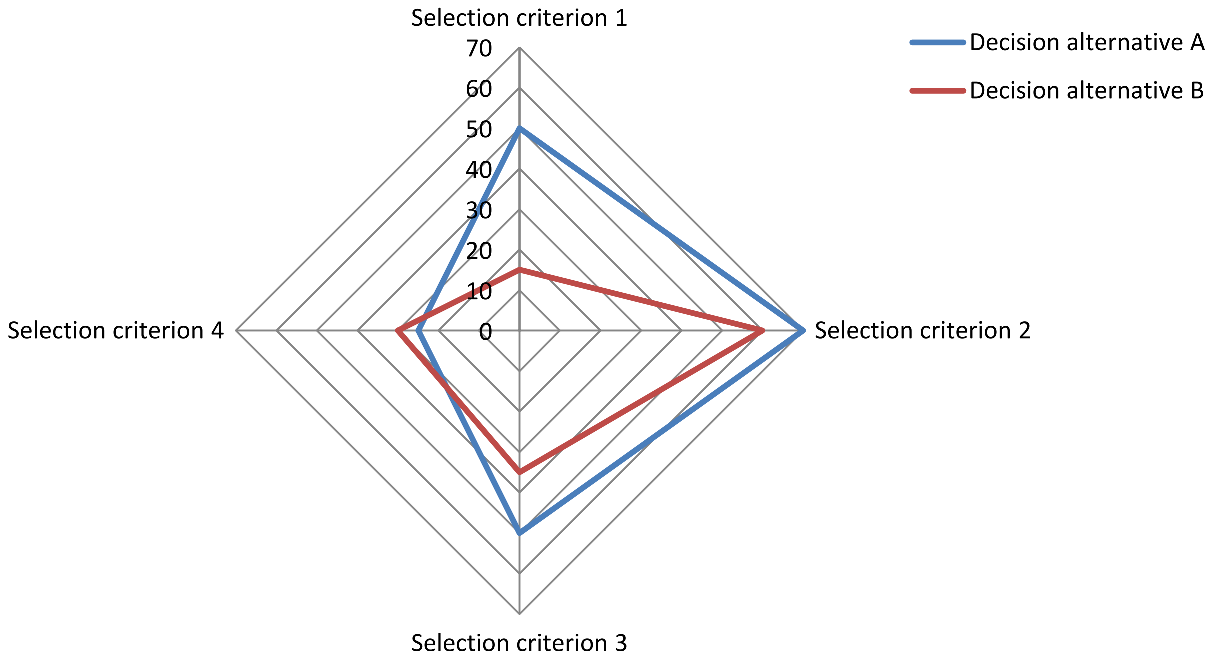

Figure 5.4: Star plot

Chapter 6

Evaluation of artifacts

The decision making method was primarily evaluated based on a case study, through thought experiment, written feedback after the analysis, and observations from the case study. The case study was conducted in a realistic setting with the intention of evaluating the artifacts with respect to the set of success criteria specified in Chapter 2. In addition, the approach to modeling in the decision making method was partially evaluated based on the same case study, through thought experiment, written feedback after the analysis, and observations from the case study. The functional fulfillment analysis was evaluated by applying examples from the case study. The approach to visualizing the decision alternatives was evaluated mainly by applying examples from the case study and verbal feedback collected after the example-based demo. We first present a brief description of the case, followed by the evaluation of the artifacts in more detail. Note that the artifacts to a certain level have been developed and evaluated in parallel.

6.1 Case description

The case study was conducted on a small case known as SensApp [50]. SensApp is an open-source service-based application used to store and exploit data collected by the Internet of Things (IoT) [50]. SensApp can register sensors, store the data collected by the sensors and notify registered clients with relevant data and information [50]. The main stakeholders involved in the context of SensApp are: sensor architect, sensors, service provider, data miner, and third party application. The sensor architect is responsible for the registration of sensors or for registering sensors. The sensors push data to the application, which indirectly trigger the sending of a notification when relevant data is pushed. The service provider is responsible for the operations and maintenance of the sensors. The data miner can query stored data, while a third party application in addition has the ability to register for notifications when relevant data is pushed. More detailed information about SensApp is provided in Appendix A.

The case study was conducted in an information security context with the objective of enhancing and improving the security of SensApp. The domain experts proposed the following decision alternatives with respect to the objective:

- **Decision alternative A: Change in infrastructure**
  Change in infrastructure means change in the technical base or fundament needed for the functioning of the service provided by SensApp.
- **Decision alternative B: Change of topology**
  Change of topology means change in the configuration of the technical base or fundament needed for the functioning of the service provided by SensApp.
- **Decision alternative C: Change of licenses**
  Change of licenses involves upgrading or purchasing enterprise and commercial software licenses for information security purposes.
- **Decision alternative D: Change of location**
  By change of location we mean geographical relocation of the infrastructure, the platform, and the environment that SensApp is based upon.
- **Decision alternative E: Update software**
  Updating the current software version of SensApp involves implementation of various security mechanisms in the already existing solution of SensApp.

More detailed information about the various decision alternatives is provided in Appendix B and C.

6.2 The process of the decision making method

In the following we present the evaluation of the process of the decision making method. This section partially covers the modeling approach, since both the process and the modeling approach were partially evaluated through the case study.

Table 6.1 outlines the overview of the process undergone during the case study. The first column addresses the specific meeting. The second column specifies the date for the specific meeting. The third column specifies the involved participants for the specific meeting. Note that the analyst, the domain experts, and the supervisor were present at all the arranged meetings. Fourth column specifies and describes the content for the specific meeting, while the fifth column shows the approximate time in terms of hours spent for the specific meeting, where A denotes the number of hours spent by the analyst and D denotes the number of man hours spent by the domain experts.

The case study was conducted in the period of April to July 2013 and consisted of mainly eight meetings involving the analyst, two domain experts, and the supervisor. The analyst and the supervisor had thorough preparation meetings before each of the meetings addressed in Table 6.1. However, these have not been taken into account with respect to the hours reported as they directly did not involve the analysis itself. The first four meetings involved presentation of the target system – SensApp – and the development of a target system description consisting of UML system models. The target system description ensured that a common understanding of the target system was obtained. The process of the decision making method was performed and conducted thereafter. Note that the last meeting was not part of the analysis itself. The last meeting involved basically an evaluation of the decision making method based on a thought experiment, followed by a written evaluation after the analysis.

Table 6.1: The process undergone during the case study

Meeting #	Date	Participants	Contents	Hours
1	April 25th 2013	Analyst and two domain experts	Presentation of SensApp and its possible application in the case study. Planning further meetings and collaboration.	A: 2,5 D: 3
2	May 3rd 2013	Analyst and two domain experts	Development of target system description. The analyst received relevant and important system documentation and system models.	A: 2,5 D: 3
3	May 14th 2013	Analyst and two domain experts	Presentation of system models developed so far. Received relevant feedback from domain experts. Brief presentation of the decision making method.	A: 3 D: 3
4	May 16th 2013	Analyst and two domain experts	Presentation of final system models and target system description. Approved by the domain experts.	A: 3 D: 3
5	July 1st 2013	Analyst and two domain experts	Presentation of the decision making method. Emphasis on Quality Analysis.	A: 2,5 D: 4

6	July 8th 2013	Analyst and two domain experts	Continued the conduction of the decision making method – emphasis on Risk and Cost Analysis.	A: 3 D: 3
7	July 16th 2013	Analyst and two domain experts	Continued the conduction of the decision making method – emphasis on Decision Making.	A: 4 D: 3
8	July 18th 2013	Analyst and two domain experts	Evaluation of the decision making method based on a thought experiment. Handed out written feedback form to be filled out by the domain experts. Agreed upon that these will be handed in online due to time shortage.	A: 4,5 D: 4

6.2.1 Setup and data collection during the case study

In addition to the analyst, the case study involved two domain experts with several years of professional experience. The domain experts represented the role of the decision maker as well throughout the case study. The domain experts had strong technological background and technical understanding. The domain experts were actively participating in the development of the target system description by providing relevant input during these meetings.

The analyst received system documentation of SensApp from the domain experts containing fundamental descriptions of the system, architectural models, CloudML [51] and Palladio [52] models of SensApp. The development of a thorough target system description was required in order to sufficiently perform the decision making method. The target system description ensured that a common understanding between the stakeholders was obtained. The analyst developed relevant UML models in close collaboration with the domain experts of SensApp by using Enterprise Architect [53]. Hence, the first four meetings involved the development of the target system description.

6.2.2 Outcomes of the case study

In this section, we summarize the outcomes of the case study. The main outcomes of the case study are the target system description and the models containing cost, risk, and quality-related information (see Appendix A, B, C, and D). We specify the main outcomes of the case study as follows:

- SensApp system description (Appendix A)
- Specification of SensApp with respect to cost, risk, and quality (Appendix B)
- Specification of decision alternatives with respect to cost, risk, and quality aspects (Appendix C)
- Outcome of Decision Making phase (Appendix D)

We have also developed a prototype tool for modeling the decision alternatives and estimating their impacts. The tool is based on Microsoft Office Excel [54] and stores all quantitative input (see Appendix D). The tool facilitates the Decision Making phase by defining the selection criteria and enabling propagation of impacts of the input on the overall performance.

6.2.3 Evaluation based on a thought experiment

We conducted a thought experiment in order to sufficiently evaluate our proposed decision making method. The thought experiment was conducted and performed with the presence of the analyst and the domain experts. The analyst proposed a set of changes that were discussed and simulated by the domain experts during the thought experiment. The domain experts were given a brief presentation and relevant handouts of the approved specification of SensApp by the analyst. For each of the thought experiments we went through the following three steps:

1. The specific change was presented by the analyst, by only providing the relevant change facts.
2. The domain experts were asked to estimate the outcome of this particular change.
3. The analyst compared the results with the outcome based on the models.

The thought experiments were as follows:

- ***Thought experiment 1 – Introduce decision alternative F: Backup of SensApp***

  The first thought experiment involved the introduction of a new decision alternative F – backup of SensApp. The question in this case was: How will decision alternative F perform compared with decision alternatives A-E in terms of cost, risk, and quality aspects?

On the basis of the change facts provided, the domain experts were able to order the various decision alternatives in terms of their performance with respect to cost, risk, and quality: (1) update software, (2) change in infrastructure, (3) backup of SensApp, (4) change of topology, (5) change of location, and (6) change of licenses.

Thereafter, the analyst developed cost, risk, and quality-related models of decision alternative F based on our decision making method. The domain experts provided relevant input regarding cost, risk, and quality aspects related to decision alternative F (see Appendix E). According to the model-based simulation, decision alternative F is the most costly one, but still remains within the allocated budget. Decision alternative F has therefore the highest cost of one point of quality compared with the other decision alternatives.

In that manner, decision alternative F performs very poorly compared with decision alternatives A-E in terms of cost, risk, and quality aspects. The results gained from the model-based simulation do not correspond with the results gained from the domain experts.

- ***Thought experiment 2 – Implement two operational environments instead of one***

  The second thought experiment involved the impact on cost elements by implementing two operational environments instead of one. The questions in this case was: What will be the impact on the total cost for the decision alternative E, and what will be the impact on the individual cost factors for the decision alternative E?

  On the basis of the change facts provided, the domain experts were able to simulate the impact on the total cost for the decision alternative E. In order to evaluate the usefulness of the cost model provided by our decision making method, the domain experts were also asked to estimate the impact on the individual cost factors for the decision alternative E.

  According to the results (see Appendix E), the total cost for decision alternative E was 1000 000 NOK according to the domain experts. However, the total cost was 1180 000 NOK according to the model-based simulation.

- ***Thought experiment 3 – Increase the weight of security to 95***

  The third thought experiment involved the impact of increasing the weight of security to 95. The question in this case was: Which decision alternative do you think will be the most desirable one, if we increase the weight of security to 95?

  On the basis of the change facts provided, the domain experts were able to simulate the impact of increasing the weight of security to 95. According to the domain experts, decision alternative E will be the most desirable one, since it performs sufficiently in terms of both reliability and security. The results gained through the thought experiment correspond with the model-based simulation (see Appendix E).

- ***Thought experiment 4 – Decrease the value of security of decision alternative E to 60 and increase the weight of reliability to 85***

  The fourth thought experiment involved the impact of decreasing the value of security of decision alternative E to 60 and increasing the weight of reliability to 85. The question in this case was: Which decision alternative do you think will be the most desirable one, if we decrease the value of security of decision alternative E and increase the weight of reliability?

  On the basis of the change facts provided, the domain experts were able to simulate the impact of decreasing the value of security of decision alternative E and increasing the weight of reliability. According to the domain experts, decision alternative C will be the most desirable one, since it performs sufficiently in terms of both reliability and security. The results gained through the thought experiment correspond with the model-based simulation (see Appendix E).

6.2.4 The selection process as described by the domain experts

During the thought experiment, the domain experts specified a pattern of decision making used specifically during the thought experiment 1. The pattern was described as follows:

1. Eliminate the decision alternative with the maximum number of catastrophic risks (can be omitted if risk function is very discriminating with respect to catastrophic risks).
2. Order the remaining decision alternatives according to total quality – set X.
3. If under budget: Check set X according to risk of one point of quality. Preserve/change the ordering from point 2 within threshold – set Y.
4. Check set Y according to cost of one point of quality. Preserve/change ordering from 3 within threshold.

6.2.5 Written feedback after the analysis

This section summarizes the written feedback received from the respondents – the domain experts – after the analysis. A written feedback form (see Appendix F) was handed out at the end of the last meeting. A full report of the written feedback is provided in Appendix G.

The overall strengths pointed out by the domain experts are the overall simplicity of the method and the practical feasibility of the process of the decision making method. Both respondents agree upon that the process is quite helpful and meaningful. According to the domain experts, the process of the decision making method was very straightforward and easy to follow.

According to R1: *"*This decision making process is an interesting endeavor in merging cost/quality trade-off with risk analysis" and "it provides an opportunity to see, side-by-side, numbers quantifying, cost, quality, and risk"*. "*To the best of my knowledge, such an analysis covering risk has never been proposed in the Software Engineering community" (R1).

The overall weaknesses pointed out by the respondents are the lack of confidence and uncertainty involved in the estimates provided by the domain experts. Another disturbing point mentioned by the both respondents is the quantification of distance between the decision alternatives. According to R1: "The two weakest aspects of the process are the definition of time and the completeness of the design alternatives identified in the first place. As far as I understand, time is a key factor here. The time spent implementing a given design alternative obviously impacts the cost, the risk, and the quality of the resulting system. It was not clear to me how we discriminated between a punctual yet very risky design alternative, and, for instance, a long lasting but less risky design alternative".

6.2.6 Observations made during the case study

In this section, we present the experiences and observations made by the analyst during the case study research.

- Initially, the analyst had difficulties understanding the target system and the terminology used by the domain experts. However, the analyst gained thorough understanding during the development of the target system description. In that manner, the target system description ensured that a common understanding was obtained by the stakeholders involved. It was therefore very important that the target system description was developed jointly.
- The target system description triggered useful discussions, which eventually led to the exclusion of misinterpretations and misunderstandings. The domain experts were actively involved and participated in discussions during the analysis of the decision making method.
- In spite of how detailed and specified the target system description is, the analyst should not develop the various models alone. Involving the domain experts during the development of the models ensured that errors and misunderstandings were revealed and resolved. The initial versions of the models contained errors and mistakes, which eventually triggered helpful discussions among the stakeholders involved.
- The various cost, risk, and quality models were developed in close collaboration with the domain experts. The domain experts had strong technical background, but still the analyst observed that it was necessary to explain the models in order to eliminate confusions. In that manner, it is important that the analyst explains the models and that potential errors are corrected immediately.
- The estimates provided by the domain experts are highly dependent on the context and circumstances of the target system under analysis. It was therefore necessary to take into account some assumptions during the case study. For instance, the

acceptance value for the various quality characteristics would be higher for medical data than for other kind of data.

- Further into the analysis of the decision making method, the domain experts discussed the need of percentages instead of absolute values regarding the acceptance values for the various cost factors. The absolute cost values for software evolution were estimated on the basis of the annual salary of a software developer. It is also important to point out that the total cost values provided by the domain experts were significantly lower than the budget allocated.

6.3 The approach to modeling in the decision making method

The approach to modeling in the decision making method was partially evaluated based on the case study on SensApp as described in the previous section. In the following we exemplify the functional fulfillment analysis. The exemplification of the functional fulfillment analysis is based on the models from the SensApp case. It is important to emphasize that the functional fulfillment analysis was in this case conducted with respect to security fulfillment. In the following we exemplify the functional security fulfillment analysis with respect to the SensApp case.

6.3.1 Functional security fulfillment analysis

By functional security fulfillment analysis we mean the analysis of (1) degree of fulfillment of functional requirements with respect to security, and (2) degree of overlap between the decision alternatives with respect to security relevant functionality. The approach makes use of feature diagrams to express the degree of fulfillment and the degree of overlap. The feature diagrams were developed in close collaboration with the domain experts. The developed feature diagrams represent security relevant features associated with the ideal security of SensApp and the various decision alternatives. We used FeatureIDE [5] to develop our feature diagrams. FeatureIDE is an Eclipse-based tool for development of feature diagrams [5]. Figure 6.1 illustrates the current security of SensApp. As depicted by Figure 6.1, the existing version of SensApp has implemented authentication and cryptography mechanisms.

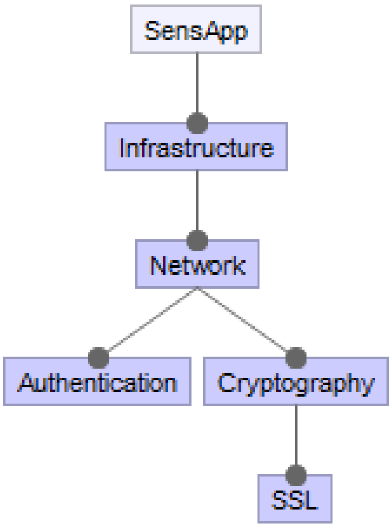

Figure 6.1: Current security of SensApp

Figure 6.2 illustrates the security relevant features associated with the ideal functionality of SensApp. The domain experts identified in particular four security domains that could be improved in terms of the objective of enhancing the security of SensApp: (1) education, (2) policies, (3) risk management, and (4) infrastructure. Furthermore, Figure 6.2 describes security mechanisms as leaf-nodes that could be implemented in order to fulfill the overall objective. We will use Figure 6.2 as a reference model during evaluation of our method for calculating the degree of fulfillment in the next section.

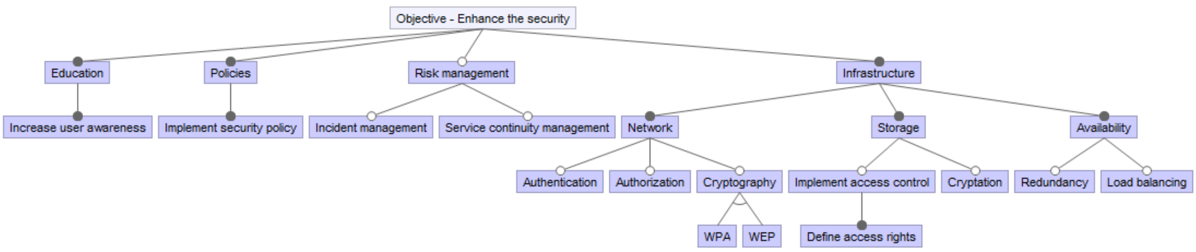

Figure 6.2: Objective - Enhance the security

Figure 6.3 illustrates the feature diagram associated with decision alternative A as specified during the case study (see Appendix B) – change in infrastructure – where infrastructure is defined as the technical base or fundament needed for the functioning of the service provided by SensApp. In that manner, Figure 6.3 illustrates the various security relevant features and mechanisms associated with SensApp after the implementation of decision alternative A. The implementation of decision alternative A will bring improvement in availability and redundancy. Change in infrastructure will in addition introduce authentication and cryptography mechanisms that will improve the security within the network. Moreover, decision alternative A will implement security-related mechanisms that will introduce service continuity management.

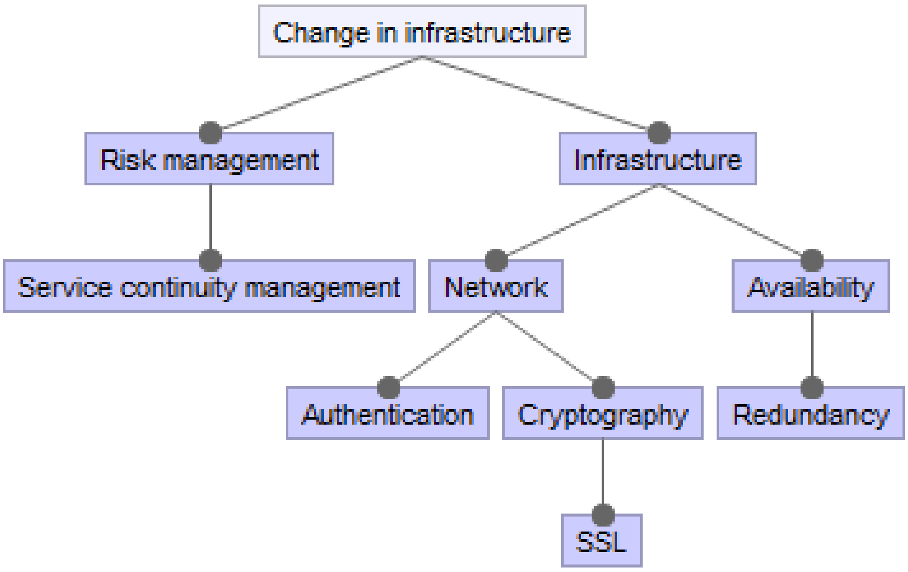

Figure 6.3: Security relevant features associated with decision alternative A

Figure 6.4 illustrates the feature diagram associated with decision alternative B as specified during the case study (see Appendix B) – change of topology – where topology is defined as the configuration of the technical base or fundament needed for the functioning of the service provided by SensApp. In that manner, Figure 6.4 illustrates the various security relevant features associated with SensApp after the implementation of decision alternative B. Similar to decision alternative A, the decision alternative B will bring improvement in availability as well. In addition to redundancy, decision alternative B will provide load balancing. Decision alternative B will also provide the implementation of both authentication and cryptography mechanisms.

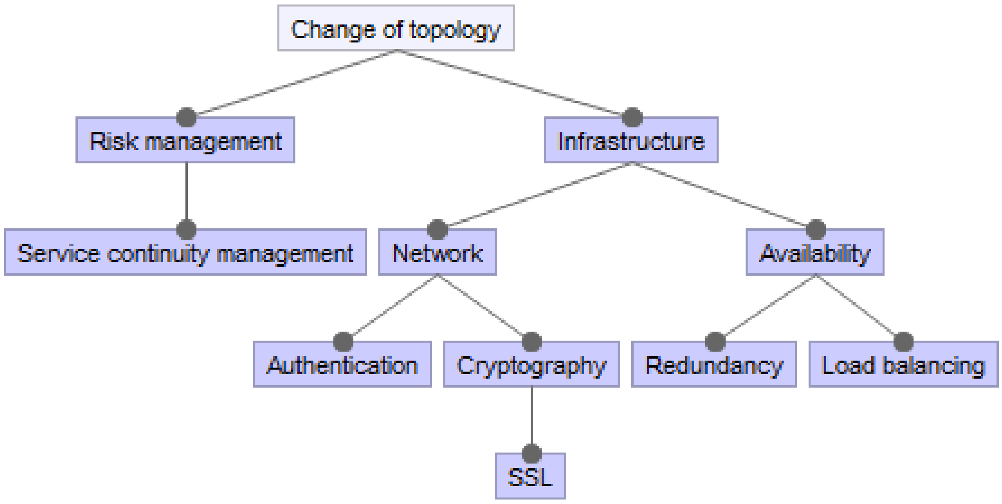

Figure 6.4: Security relevant features associated with decision alternative B

Figure 6.5 illustrates the feature diagram associated with decision alternative C as specified during the case study (see Appendix B) – change of licenses. Decision alternative C involves upgrading or purchasing enterprise and commercial software licenses for information security purposes. In that manner, Figure 6.5 illustrates the various security relevant features associated with SensApp after the implementation of decision alternative C. By upgrading or purchasing enterprise and commercial software licenses, there will be a need for increasing user awareness and implementing security policies. Moreover, decision alternative C will implement various security mechanisms for securing the network and the storage. In addition, it is possible to purchase licenses from external information security vendors for monitoring and management of security-related incidents.

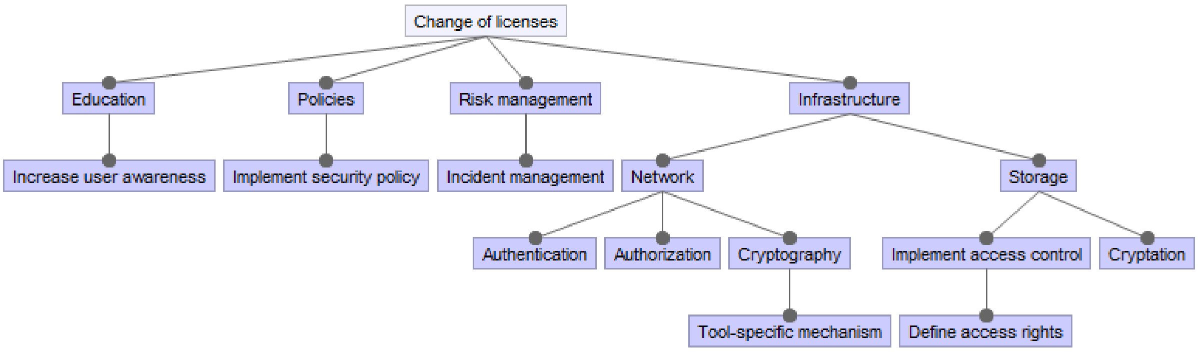

Figure 6.5: Security relevant features associated with decision alternative C

Figure 6.6 illustrates the feature diagram associated with decision alternative D as specified during the case study (see Appendix B) – change of location. By change of location we mean geographical relocation of the infrastructure, the platform, and the environment that SensApp is based upon. Relocation of Information Technology services often introduce legal issues, therefore there will be a need of increasing user awareness and implementing security policies. Furthermore, decision alternative D will bring improvement in network security by implementing various authentication and cryptography mechanisms. Figure 6.6 illustrates the various security relevant features associated with SensApp after the implementation of decision alternative D.

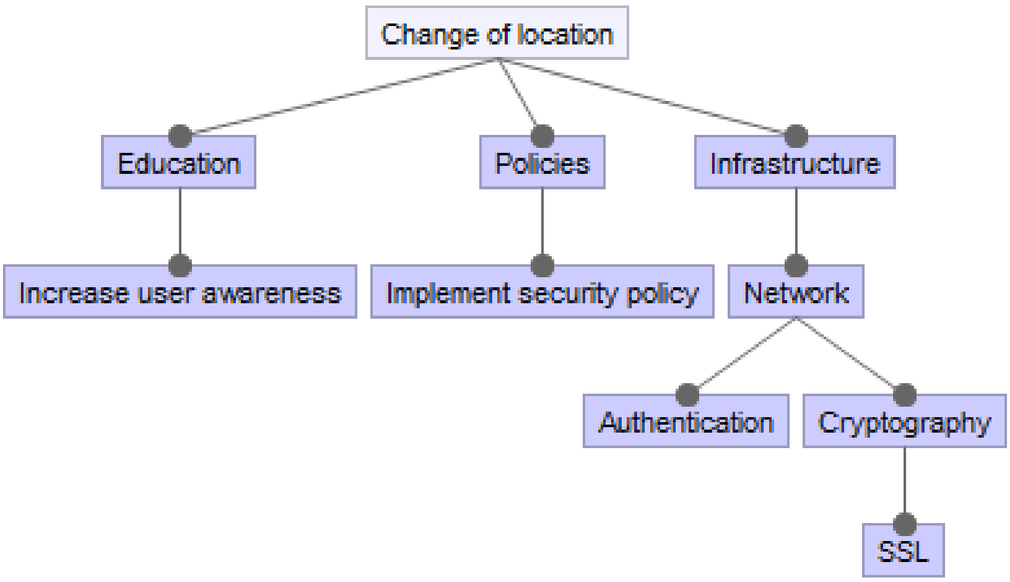

Figure 6.6: Security relevant features associated with decision alternative D

Figure 6.7 illustrates the feature diagram associated with decision alternative E as specified during the case study (see Appendix B) – update software. By updating the current software version of SensApp, it will be possible to implement various security mechanisms in the already existing solution of SensApp. In that manner, decision alternative E will implement various security mechanisms for providing more robust security of the network and the storage. Figure 6.7 illustrates the various security relevant features associated with SensApp after the implementation of decision alternative E.

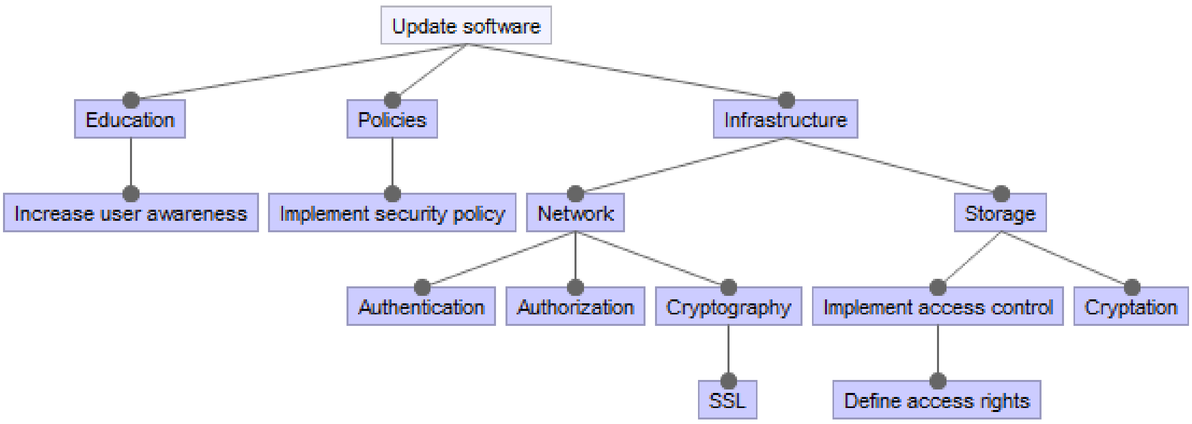

Figure 6.7: Security relevant features associated with decision alternative E

6.3.1.1 The degree of fulfillment

In this section, we present the example-based evaluation of our proposed method for calculating the degree of fulfillment. The examples rely on the models from the case study on SensApp. The degree of fulfillment reflects the coverage of security features related to the various decision alternatives. We assigned weights to the various security features described by the feature diagram representing the ideal functionality of SensApp (Figure 6.2). A weight denotes the importance of a security feature with respect to the parent node. In this case, the security features were assigned weights according to the scale specified in Figure 6.8. The scale was agreed upon and defined by the domain experts.

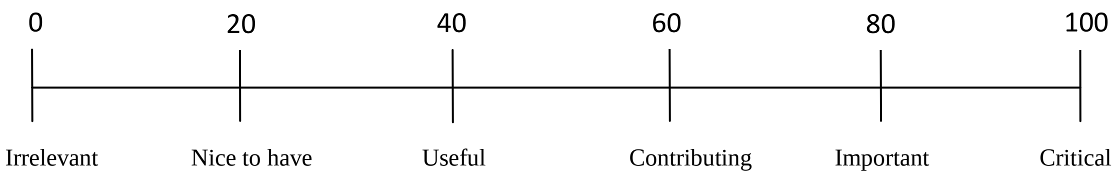

Figure 6.8: Scale for assigning weights

The weights should propagate to the overall security of SensApp provided by the respective decision alternatives. Assigning weights was done based on a top-down approach. The feature diagrams representing the various decision alternatives inherit the weights assigned to the objective (Figure 6.9). This is possible since the feature diagrams representing the various decision alternatives are sub-graphs of the feature diagram representing the objective of SensApp. Feature diagrams containing the objective of SensApp and decision alternative A with assigned weights are presented in Figure 6.9 and 6.10, respectively.

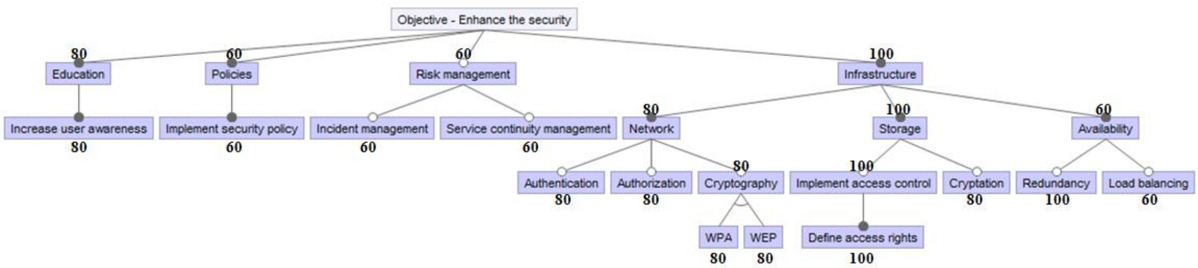

Figure 6.9: Objective with assigned weights

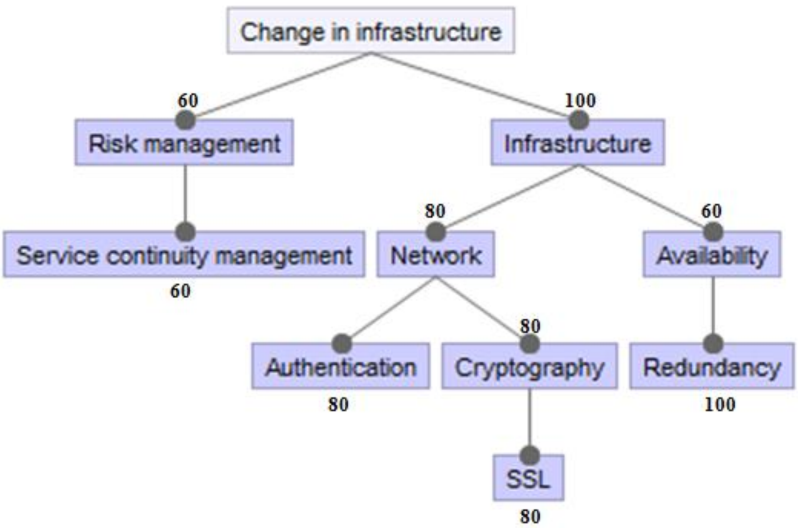

Figure 6.10: Decision alternative A with assigned weights

The sub-features of infrastructure in Figure 6.9 represent three mandatory sub-groups – namely network, storage, and availability. It is important to point out that the weight assigned to infrastructure represents the importance of infrastructure given the overall objective, while the weights assigned to the various sub-features of infrastructure represent the importance given the parent-feature. Network is therefore important while storage is critical given the infrastructure of the information system in question. The sub-features of an alternative-relationship should be assigned the same weight, since they all are equally representative for the parent-feature. In that manner, both WEP and WPA are important security relevant features given the feature of cryptography. The difference between mandatory and optional features is ensured and maintained through the assigned weights. The degree of fulfillment achieved by decision alternative A can be obtained as follows:

$$\frac{0}{300}+\frac{0}{300}+\frac{60}{300}\left(\frac{60}{120}\right)+\frac{100}{300}\left(\frac{80}{240}\left(\frac{80}{240}+\frac{0}{240}+\frac{80}{240}\left(\frac{80}{80}\right)\right)+\frac{0}{240}+\frac{60}{240}\left(\frac{100}{160}+\frac{0}{160}\right)\right)\approx 0{,}226$$

The calculation is based on a top-down approach, where the weight of each node is aggregated by the principle of normalization. In that manner, decision alternative A has achieved 22.6% degree of fulfillment. We will walk through the calculation in detail. The first term in the calculation represents the node of education, where the denominator represents the sum of the weights in the first level in Figure 6.9. The numerator is zero since the node of education is not represented by decision alternative A. Similar reason yields for the second term in the calculation.

The third term represents the node of risk management, where the numerator represents the assigned weight and the denominator represents the sum of the weights in the first level of the feature diagram in Figure 6.9. Further, the node of risk management involves implementation of incident management and service continuity management. Decision alternative A does not provide incident management, and we therefore only take into account service continuity management in the calculation. The numerator in the aggregated term represents the assigned weight of service continuity management, while the denominator represents the sum of the assigned weight of both incident management and service continuity management.

The calculation is similar for the node representing infrastructure. However, it is important to notice that only one of the sub-features in an alternative-relationship has been taken into account in the calculation. In that manner, the calculation is only based on one of the assigned weights to the alternative-relationship consisting of WPA and WEP. Since the sub-features of an alternative-relationship should be assigned the same weight, the denominator should represent the assigned weight of the parent-feature.

The proposed method can similarly be used to calculate the degree of fulfillment achieved by decision alternatives B-E. The corresponding calculation for the overall decision alternatives results in the following fulfillment values:

- Decision alternative B: 0,257
- Decision alternative C: 0,917
- Decision alternative D: 0,541
- Decision alternative E: 0,717

6.3.1.2 The degree of overlap

In this section, we present the degree of overlap between the decision alternatives. The degree of fulfillment tells nothing about the overlap between the decision alternatives. We use the same notion of degree of fulfillment to generate degree of overlap obtained by the various decision alternatives. The degree of overlap has been calculated by having the various decision alternatives as reference models. The columns in Table 6.2 illustrate the reference models. The degree of overlap explains to which extent two decision alternatives provide the same security-related mechanisms. Table 6.2 presents the degree of overlap obtained by the decision alternatives.

Table 6.2: Degree of overlap between the decision alternatives

	A	**B**	**C**	**D**	**E**
A		0,900	0,099	0,417	0,123
B	1		0,099	0,417	0,123
C	0,357	0,357		1	1
D	0,357	0,357	0,565		0,707
E	0,357	0,357	0,800	1	

The intuition of the degree of overlap is to identify decision alternatives with similar characteristics and features. According to Table 6.2, we observe that the security-related mechanisms provided by decision alternative A are also provided by decision alternative B. However, decision alternative B provides load balancing as well (see Figure 6.4). In that manner, it would be reasonable to exclude decision alternative A.

Figure 6.11 illustrates to a certain extent the degree of fulfillment and the degree of overlap obtained by the decision alternatives from the SensApp case as presented in the previous sections. The size of the elements in Figure 6.11 depicts the degree of fulfillment, while the placement of the elements depicts to what extent the various decision alternatives overlap with respect to security features and functionality. According to Figure 6.11, the security-related mechanisms provided by decision alternatives D and E are covered by decision alternative C. This can also be observed by Table 6.2.

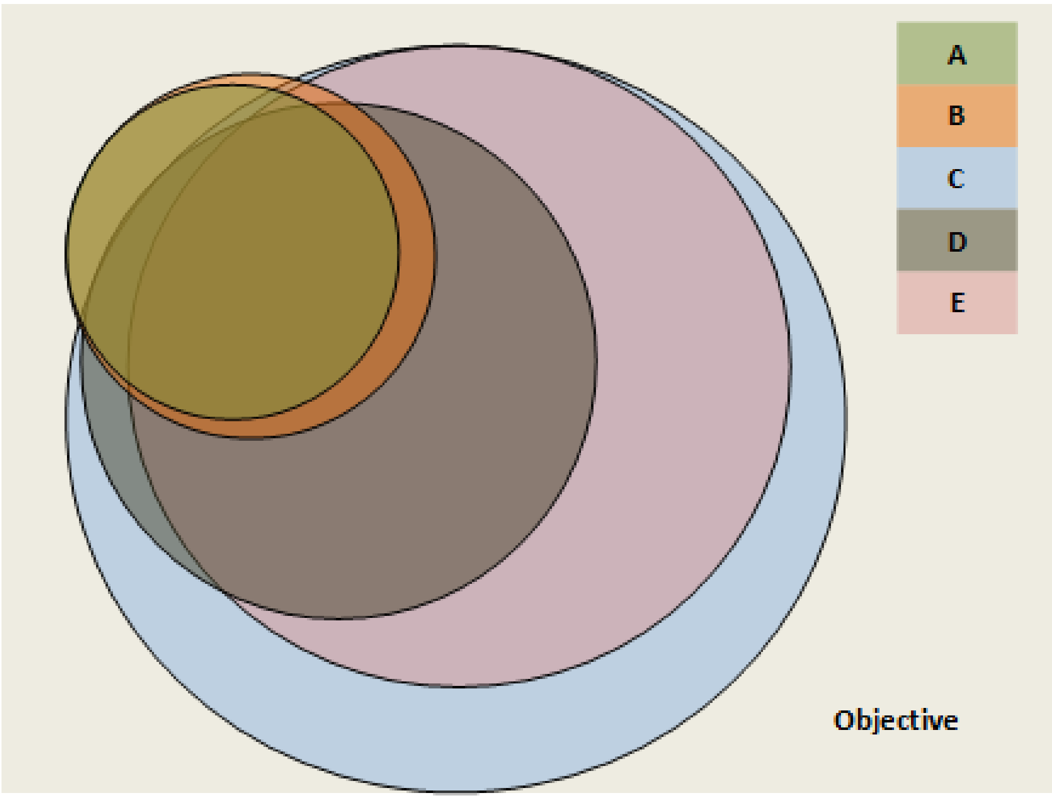

Figure 6.11: Degree of fulfillment and degree of overlap

6.3.2 Observations

In this section, we present the experiences and observations made by the analyst during the development of the feature diagrams in the context of SensApp.

- Initially, there was a discussion in the group regarding the syntax of feature diagrams. However, both domain experts had sufficient experience with feature modeling. The main confusions and misunderstandings were about the alternative- and or-relationship. The misinterpretations and misunderstandings triggered useful discussions, which eventually ensured that a common understanding of feature modeling was obtained by the stakeholders involved. In that manner, the domain experts were actively involved and participated in discussions.
- The decision alternatives were briefly specified during the case study. In that manner, the decision alternatives had to be refined and specified in more detail by the domain experts.
- In spite of how detailed and specified the target system description is, the analyst should not develop the feature diagrams alone. Involving the domain experts during the development of the feature diagrams ensured that errors and misunderstandings were revealed and resolved. The initial versions of the feature diagrams contained errors and mistakes, which eventually triggered helpful discussions among the stakeholders involved.
- The uncertainty around assigning of weights stimulated a lot of useful discussions between the stakeholders involved. As a result of the discussions, a scale (Figure 6.8) specifying the assigning of weights was developed in close collaboration with the domain experts. The scale was agreed upon and defined by the domain experts.

6.4 The approach to visualizing the decision alternatives

In this section, we provide the evaluation of the approach to visualizing the decision alternatives. The approach to visualizing the decision alternatives was evaluated by exemplifying the approach on models from the SensApp case. Section 6.4.1 presents the exemplification of our approach to visualizing the decision alternatives. Section 6.4.2 provides the verbal feedback collected after the example-based demo.

6.4.1 Visualizing the decision alternatives

In this section, we present our proposed approach to visualizing the decision alternatives. The approach to visualizing the decision alternatives provides graphical representation of the decision alternatives and their overall performance with respect to cost, risk, quality, and degree of fulfillment. The approach to visualizing the decision alternatives provides support in determining the preferred decision alternatives. We here exemplify our proposed approach to visualizing the decision alternatives in the context of the SensApp case study.

Table 6.3 illustrates the overall performance of the decision alternatives with respect to cost, risk, quality, and degree of fulfillment. Total cost, total quality, and the weight of risks is obtained from the case study on SensApp (see Appendix D), while the degree of fulfillment is obtained from the results presented in Section 6.3. The total quality reflects the non-functional requirements achieved by the decision alternatives, while the degree of fulfillment reflects the security features and functionality related to the various decision alternatives. The degree of fulfillment represents the coverage achieved by each decision alternative regarding security features.

Table 6.3: Performance with respect to cost, risk, quality, and degree of fulfillment

Decision alternative	**Total cost** (total budget: NOK 1105 000)	**Total quality**	**Weight of risks**	**Degree of fulfillment**
A	720 000	62,5	269	22,6
B	740 000	59,7	170	25,7
C	770 000	61,7	411	91,7
D	890 000	62,7	380	54,1
E	855 000	68,8	436	71,7

The values of total quality and degree of fulfillment are normalized and within the range of [0, 100]. According to Ravindran [1]: "A common problem in multiple criteria decision making with the use of differing units of evaluation measures is that relative rating of alternatives may change merely because the units of measurements have changed. This issue can be addressed by normalization. Normalization allows intercriterion comparison". In that manner, we normalize the total cost values with respect to the total budget. Hence, the normalized total cost value x' is given as follows:

$$x' = \frac{total\ cost}{total\ budget}$$

Similarly, we normalize the weight of risks with respect to the total risk value. The normalized values are obtained by dividing the weight of risks in Table 6.3 by the total risk value of 1347 (see Appendix D). In order to obtain the normalized values in the [0, 100] range, the values are multiplied by 100. Hence, Table 6.4 presents the obtained normalized values for total cost and weight of risks in the [0, 100] range.

Table 6.4: Normalized values for total cost, total quality, weight of risks, and degree of fulfillment

Decision alternative	Total cost	Total quality	Weight of risks	Degree of fulfillment
A	65,2	62,5	20,0	22,6
B	67,0	59,7	12,6	25,7
C	70,0	61,7	30,5	91,7
D	80,5	62,7	28,2	54,1
E	77,4	68,8	32,4	71,7

Total quality and degree of fulfillment are both benefit criteria in which more is better, while total cost and weight of risks are cost criteria in which less is better. We address this issue by transforming total cost and weight of risks to equivalent benefit criteria by taking the inverse of them. In order to obtain the inverse values in the [0, 100] range, the values are multiplied by 1000. Table 6.5 presents total cost, total quality, weight of risks, and degree of fulfillment as benefit criteria.

Table 6.5: Total cost, total quality, weight of risks, and degree of fulfillment as benefit criteria

Decision alternative	Total cost'	Total quality	Weight of risks'	Degree of fulfillment
A	15,3	62,5	50,1	22,6
B	14,9	59,7	79,2	25,7
C	14,4	61,7	32,8	91,7
D	12,4	62,7	35,4	54,1
E	12,9	68,8	30,9	71,7

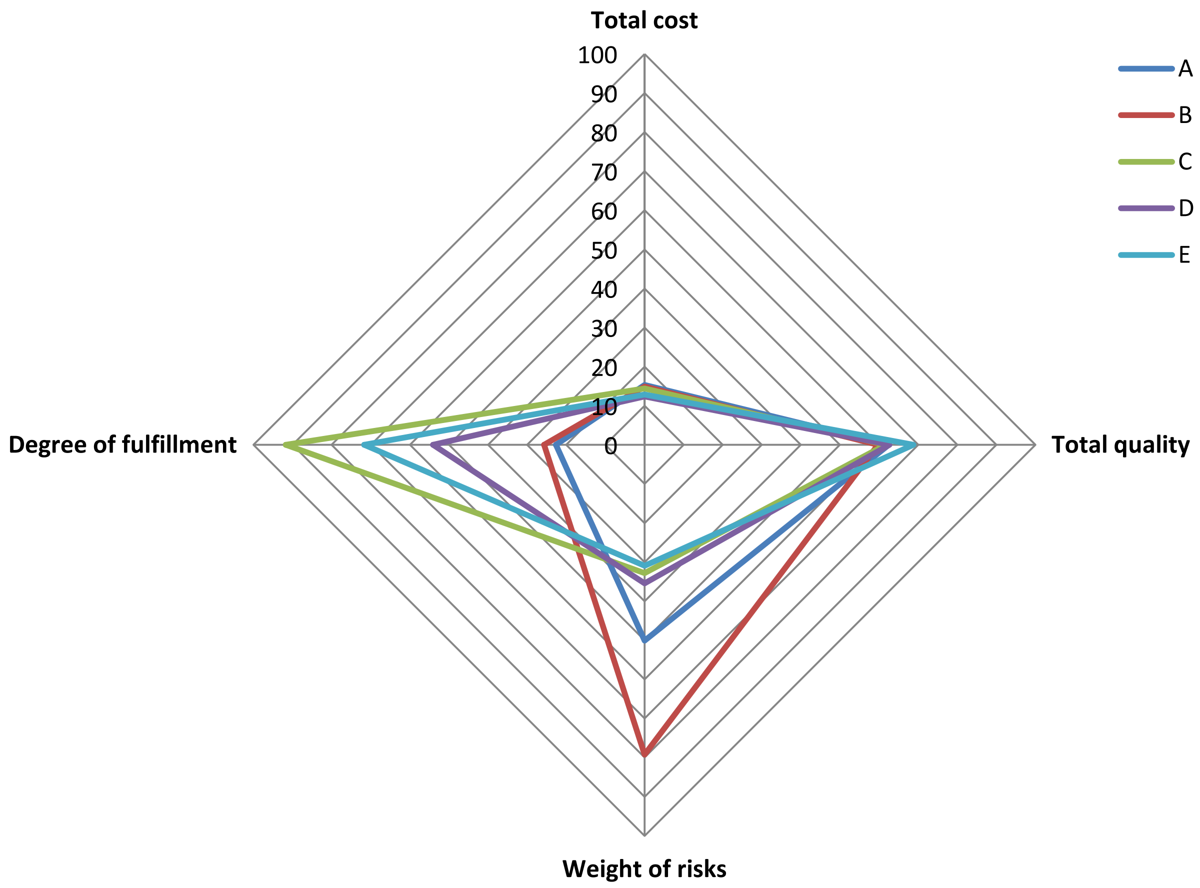

Figure 6.12: Overall performance of the decision alternatives

Figure 6.12 illustrates the overall performance of the decision alternatives with respect to the selection criteria presented in Table 6.5. The colors represent the various decision alternatives. A decision alternative that fulfills the maximum level of total cost, total quality, weight of risks, and degree of fulfillment defines the preferred decision alternative. In that manner, the star with the largest area will determine the preferred decision alternative. The size of graph areas associated with the various decision alternatives are as follows:

- Decision alternative A: 2782,8
- Decision alternative B: 4018,1
- Decision alternative C: 3620,2
- Decision alternative D: 2791,5
- Decision alternative E: 3077,0

It is important to emphasize that this is only an exemplification of our proposed approach for visualizing the decision alternatives. The size of graph area does not reflect the importance of the various selection criteria. We have for simplicity assumed that the various selection criteria are equally important for the decision making problem in question. In practical, it might be that one decision criterion is more important than another decision criterion. The size of graph area is therefore only meaningful as a measurement for the preferred decision alternative if only the weights of selection criteria are taken into account.

6.4.2 Verbal feedback from the domain experts

This section summarizes the verbal feedback received from the domain experts on our proposed approach to visualizing the decision alternatives. The overall feedback pointed out by the domain experts focused on the need for overall simplicity of the proposed approach. Both domain experts agree that the proposed approach for visualizing the decision alternatives is quite helpful and meaningful in relation to our decision making method.

- According to the domain experts, the graphical representation presented by Figure 6.12 is straightforward, but still provides an extensive and broad overview of the trade-offs.
- Figure 6.12 illustrates the total cost, total quality, weight of risks, and degree of fulfillment as axes, while the colored graph areas represent the various decision alternatives. The domain experts preferred the various decision aspects as axes rather than the decision alternatives. According to the domain experts, having the graphs representing the decision alternatives makes it easier to distinguish the alternatives.
- According to the domain experts, the number of catastrophic risks presented in Table D.8 (see Appendix D) does not provide any relevant information and could therefore be ignored.
- As pointed out by the domain experts, the model provides a comprehensible and understandable overview of the decision alternatives and their performance with respect to the selection criteria.
- According to the domain experts, the proposed approach facilitates the Decision Making phase of our decision making method by graphically visualizing the

performance of the various decision alternatives in terms of cost, risk, quality, and degree of fulfillment.

- The integration of the approach to visualizing the decision alternatives to our decision making method provides valuable information and thus improves and strengthens our decision making method.

Chapter 7

Evaluation with respect to success criteria

Chapter 1 presented the main objective and contribution of this thesis. In Chapter 2 we refined the objective for the decision making method into a set of success criteria with respect to our three artifacts: (1) the process of the decision making method, (2) the approach to modeling in the decision making method, and (3) the approach to visualizing the decision alternatives. In the following we discuss to what extent the success criteria have been fulfilled by the specific artifact in question.

7.1 The process of the decision making method

Success criterion 1 - *The process of the decision making method facilitates the making of informed decisions.*

The case study, the thought experiment, and the written feedback gained from the domain experts indicate that the process of the decision making method provides a structured guidance and support towards informed decision making in an information security context. The domain experts were able to distinguish between the various security measures and their implications with respect to cost, risk, quality, and degree of fulfillment. The domain experts were able to substantiate the decisions made based on the models. Thus, we have some initial indications of feasibility of the process. The written feedback also indicated usefulness of the process.

Success criterion 2 - *The process of the decision making method can be applied in a real-life setting within limited resources.*

The evaluation of the case study indicates that the process can be applied on a realistic information system within limited resources. According to the domain experts, the process of the decision making method was helpful and useful for understanding the impact of the various decision alternatives with respect to cost, risk, quality, and degree of fulfillment. The analyst was able to conduct and perform the process within allocated resources in a realistic industrial context with acceptable effort. However, it is important to emphasize that SensApp is a small information system with minimal complexity. It may therefore be argued that SensApp might not have been a realistic target system for our research and analysis. However, the results from our case study do indicate practical feasibility of our process. Moreover, the process of the decision making method was conducted within a reasonable time period. It is worth mentioning that this is the first time the process of the decision making method was performed and applied on an information system. In that manner, it is assumed that the time spent on performing and conducting the decision making method would decrease with further experience. The current results indicate that the process of the decision making method can be applied in a real-life setting within limited resources.

Success criterion 3 - *The process of the decision making method is sufficiently comprehensible to the stakeholders.*

The stakeholders were actively participating in the analysis and were able to use the process of the decision making method correctly with correct interpretation. According to the written feedback from the domain experts, the process was straightforward and fairly easy to understand. However, comprehensibility of the process may vary among the participants depending on the degree of technical background. In this case, the stakeholders involved had a strong technical background. The analyst developed the decision making method and therefore had complete insight into the process of the decision making method. It may therefore be argued that the comprehensibility of the process has not been sufficiently evaluated to an analyst in general. However, current results indicate that the process of the decision making method is sufficiently comprehensible to the stakeholders involved.

7.2 The approach to modeling in the decision making method

Success criterion 4 - *The approach to modeling in the decision making method provides sufficiently correct and certain set of models.*

This success criterion implies that the set of models are unbiased as well as sufficiently accurate and precise for the purpose intended, and should substantiate and support the decisions made by the decision maker. The thought experiment has given some indications of correctness of the models. However, with respect to the evaluation we have conducted, it is difficult to conclude anything about the correctness and certainty of the models. Moreover, the requirements for correctness would vary from case to case (e.g., medical data would require higher level of correctness).

Success criterion 5 - *The approach to modeling in the decision making method provides sufficiently expressive set of models.*

The evaluation indicates that the models were able to capture cost, risk, and quality-related information with respect to SensApp. In that manner, the set of models were sufficiently expressive in our specific case. However, on the basis of our evaluation, it is difficult to say if this would normally be the case.

Success criterion 6 - *The approach to modeling in the decision making method is sufficiently comprehensible to the stakeholders.*

The stakeholders were actively participating in the analysis and were able to use the models correctly with correct interpretation. The domain experts were able to contribute to modeling, agree upon a common set of the models, and approve them. Comprehensibility of the models by both domain experts and the analyst needs to be further evaluated. As a possible measure to improve it in the future, detailed guidelines and tool support should be developed.

7.3 The approach to visualizing the decision alternatives

Success criterion 7 - *The approach to visualizing the decision alternatives provides one viewpoint for decision making.*

The domain experts were able to reason around the decision alternatives based on our approach to visualizing the decision alternatives. According to our observations, the domain experts were able to distinguish between the various decision alternatives and their implications with respect to cost, risk, quality, and degree of fulfillment. It may be argued that the approach to visualizing the decision alternatives might get more complex with increasing number of decision alternatives. However, current results indicate that the approach to visualizing the decision alternatives facilitates multiple criterion decision problems and provides one viewpoint for decision making.

Success criterion 8 - *The approach to visualizing the decision alternatives is sufficiently comprehensible.*

The domain experts were actively participating during the development of the approach to visualizing the decision alternatives and were able to use the model correctly with correct interpretation. According to the domain experts, the approach is useful in the sense that it provides comprehensible and graphical insight into the overall performance of the decision alternatives. However, comprehensibility of the approach may vary among the participants depending on the degree of technical background. In this case, the domain experts involved had a strong technical background. Current results indicate that the approach to visualizing the decision alternatives is sufficiently comprehensible to the stakeholders involved.

Success criterion 9 - *The approach to visualizing the decision alternatives is sufficiently correct and certain.*

The weakest point with our approach to visualizing the decision alternatives is the uncertainty regarding the estimates provided by the domain experts. As pointed out earlier, the decision making method is only interested in the deviation between the decision alternatives in terms of cost, risk, and quality aspects. Furthermore, our proposed approach is only an exemplification. As future work, we should include uncertainty in the approach.

7.4 How our artifacts relate to state of the art

In the following we discuss how our artifacts relate to state of the art. We compare our proposed decision making method with relevant parts of state of the art presented in Chapter 4. Considering our decision making method in general, we have to a certain degree employed established and existing concepts, terminology, methods, and notations.

According to state of the art, there are five common techniques for cost estimation (see Section 4.1.3): expert judgment, estimation by analogy, decomposition, models, and pricing to win. Considering the context and the nature of our research, the estimates provided in terms of cost, risk, and quality aspects were primarily based on expert judgment. The domain experts provided estimates based on their experience. In that manner, the quality of the estimations relies heavily on the experts and their breadth of experience. Considering the Cost Analysis phase, the domain experts utilized our cost models in order to provide sufficient cost estimations. The cost model is based on decomposition, where the total cost is decomposed into various cost types. The cost estimates of the various cost types are then combined to produce the total cost of the decision alternatives.

Considering the Risk Analysis phase and the Quality Analysis phase, our proposed decision making method applies the existing notations and terminology used in both CORAS [7] and PREDIQT [36]. CORAS and PREDIQT provide in-depth content related to risk and quality analysis. We have to a certain degree employed the concepts provided by CORAS and PREDIQT with respect to risk and quality analysis.

Our approach to modeling in the decision making method makes use of existing modeling techniques and concepts, such as tables and feature modeling [5]. The adopted modeling techniques are well-known and chosen with objective to be familiar and comprehensible to non-technical users. The models containing cost, risk, and quality-related information rely heavily on tables. The approach to modeling in the decision making method makes use of feature diagrams [5] in order to address and express the overlap between the decision alternatives. Feature diagrams provide insight into the features and mechanisms implemented by the various decision alternatives. To best of our knowledge, there is no such existing method for functional fulfillment analysis.

The approach to visualizing the decision alternatives makes use of star plot [48] to graphical visualize the overall performance of the decision alternatives. There are several important factors that must be considered when selecting an appropriate visualization. In our case, we emphasized that the visualization should support multiple criteria decision problems and provide one overview for decision making. Line charts, scatter plots, bubble charts, bar charts, histograms, pie charts, and timeline charts are not applicable for visualizing multivariate data. The usage of these techniques would require the decision maker to rely on multiple set of diagrams. Hence, the notion of star plot was applicable in the context of our decision making method.

Chapter 8

Threats to validity and reliability

In this chapter, we discuss some of the matters that might have influenced the validity and reliability in our research. We address reliability threats and four types of validity threats [12]: conclusion validity, construct validity, external validity, and internal validity. According to Runeson and Höst [12]: "The validity of a study denotes the trustworthiness of the results, to what extent the results are true and not biased by the researchers' subjective point of view". In general, the largest concern regarding validity is the lack of confidence in the estimates provided by the domain experts. The estimates provided by the domain experts are highly dependent on subjective matters.

Reliability is measured by the assumption that the research can be conducted with the same repeated tasks and end with the same results [12] [55]. There were a large number of contextual factors influencing our research, such as: the research setting, the research method, the target system under analysis, and the participants involved. Our research was highly dependent on subjective estimates provided by the domain experts. For that reason, we have reported the setting and context of the research, assumptions and interpretations made during the research, and methods used for collecting and analyzing the data. It is not certain that our proposed decision making method could be performed with the same repeated tasks and especially end with the same results. Although our results indicate practical feasibility of our proposed decision making method, further evaluation is needed in order to claim reliability. Further evaluation was not possible due to the resource and time constraints related to our research.

Conclusion validity is defined as "the validity of inferences about the correlation (covariation) between treatment and outcome" [55]. We have compensated the conclusion validity by involving domain experts with in-depth technological background. We ensured a certain degree of triangulation by using multiple sources of evidence in order to strengthen our results. The sources of evidence include: target system descriptions, UML system models, presentation slides, meeting notes, written evaluation after the analysis, and observations made during the analysis.

Construct validity is concerned with to "what extent the operational measures that are studied really represent what the researcher have in mind and what is investigated according to the research questions" [12]. In other words, construct validity concerns to which extent our models describe what they are supposed to describe. A threat to construct validity is the aggregation of cost, risk, and quality. The aggregation of cost, risk, and quality is a rough simplification in our case, and should be addressed as future work. However, the domain experts participated throughout the development of the models and their terminology, and thus contributed to consistency of the models.

External validity is concerned with to "what extent it is possible to generalize the findings, and to what extent the findings are of interest to other people outside the investigated case" [12]. It is important to emphasize that our case study research was based on a small information system with limited complexity. In that manner, it may be argued that SensApp was not a representative case for our research. However, the size and the complexity of SensApp were suitable for our research considering resource and time limitations. Moreover, the functional fulfillment analysis was conducted with respect to only security, which in turn is a restriction considering our definition of the functional fulfillment analysis. Although our results indicate practical feasibility of our proposed decision making method, further evaluation is required to claim external validity.

Internal validity is defined as "the validity of inferences about whether observed covariation between A (the presumed treatment) and B (the presumed outcome) reflects a causal relationship from A to B as those variables were manipulated or measured" [55]. It may be argued that there exists a certain correlation internally between the cost, risk, and quality aspects involved. A specific cost variable might have an internal correlation with another cost variable without the researcher being aware of it. Similar association might also yield for the risk and quality variables involved. Hence, our research lacks the treatment of joint variables. In that manner, it might be that the cost, risk, and quality aspects do not involve disjoint variables, and thus there exist some hidden dependencies without the researcher being aware of them.

Chapter 9

Conclusions and future work

The objective of this thesis was to propose a decision support method considering three aspects: cost of implementing the decision alternatives, the risks associated with the decision alternatives, and the overall effect on system quality. The proposed decision making method should be:

- useful in the sense that it facilitates decision making;
- cost-effective; and
- comprehensible for the stakeholders involved.

Considering the proposed decision making method, we have throughout this thesis primarily focused on the following three artifacts: (1) the process of the decision making method, (2) the approach to modeling in the decision making method, and (3) the approach to visualizing the decision alternatives. We consider the three artifacts to be the main building blocks of the proposed decision making method. We have through this thesis presented the developed decision making method, and reported on the results of its evaluation.

We evaluated the decision making method based on a case study with respect to a set of pre-defined success criteria. Apart from the case study, the evaluation involved thought experiment, observations made during the analysis, exemplifications, written and verbal feedback. The decision making method was developed during the case study research. Results indicate that the proposed method facilitates decision making within Information Technology. The evaluation has provided useful insights into strengths and weaknesses of the method and suggested directions for future research and improvements.

The results of the evaluation indicate practical feasibility of the decision making method in a realistic context. The approach to modeling in the decision making method is able to express cost, risk, and quality aspects. In addition, the approach to modeling in the decision making method provides a functional fulfillment analysis. The functional fulfillment analysis involves the analysis of (1) degree of fulfillment of functional requirements with respect to objective, and (2) degree of overlap between the decision alternatives with respect to the functional part of objective. Additionally, we were able to visualize the overall performance of the decision alternatives by employing our approach to visualizing the decision alternatives. Furthermore, the results of the evaluation indicate that the decision making method can be conducted with limited resources. However, our findings and results involve threats to validity and reliability, such as uncertainty in the estimates and possible causal relationship internally between the variables.

Future work should address the uncertainty involved in our proposed decision making method. The largest concern is the lack of confidence in the estimates. The main threat to our findings is that they are dependent and based on subjective matters. In that manner, further evaluation with proper handling of uncertainty is required to confirm and claim the results of our research. Future work should also address the robustness of the calculations involved in our decision making method. By robustness we mean the extent to which the overall picture of the decision alternatives and their performance would change if the input estimates change. For instance, how large should a change of the input estimates be in order to alter the overall performance with respect to our four aspects (cost, risk, quality, and degree of fulfillment) or even the ordering of the decision alternatives suggested by our decision making method. Additionally, further evaluation is required to evaluate the practical feasibility of our proposed decision making method, perhaps on a more complex information system and within a different domain. Directions for future work should include the development of a tool support for the decision making method. In addition, a stepwise manual with detailed guidelines for conducting the proposed decision making method is required to ensure sufficient practice of our method.

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Appendix A

SensApp system description

The initial meetings were primarily based on developing a target system description. In this appendix, we present the UML system models that were developed by the analyst in close collaboration with the domain experts. It is worth mentioning that some of the UML system models were developed based on a nursing home example, as it was easier to understand the target system by a realistic example. The nursing home usage scenario involves the monitoring of patients with heart weaknesses. In that manner, the patients are equipped with sensors sending relevant health data to for example the physician. The physician can subscribe to SensApp and be notified when abnormal activity is identified.

The component diagram on Figure A.1 illustrates the main four services involved in SensApp: storage, registry, notifier, and dispatcher. The storage mechanism implements the database service and is responsible for storing sensor data. The registry mechanism is responsible for storing information about the sensors involved in the application, such as descriptions about the sensors, creation date etc. The notifier is mainly used by third party applications to subscribe for notification services. The dispatcher receives data from the sensors involved, stores the data in the database service, and generates the notification mechanism when relevant data are pushed.

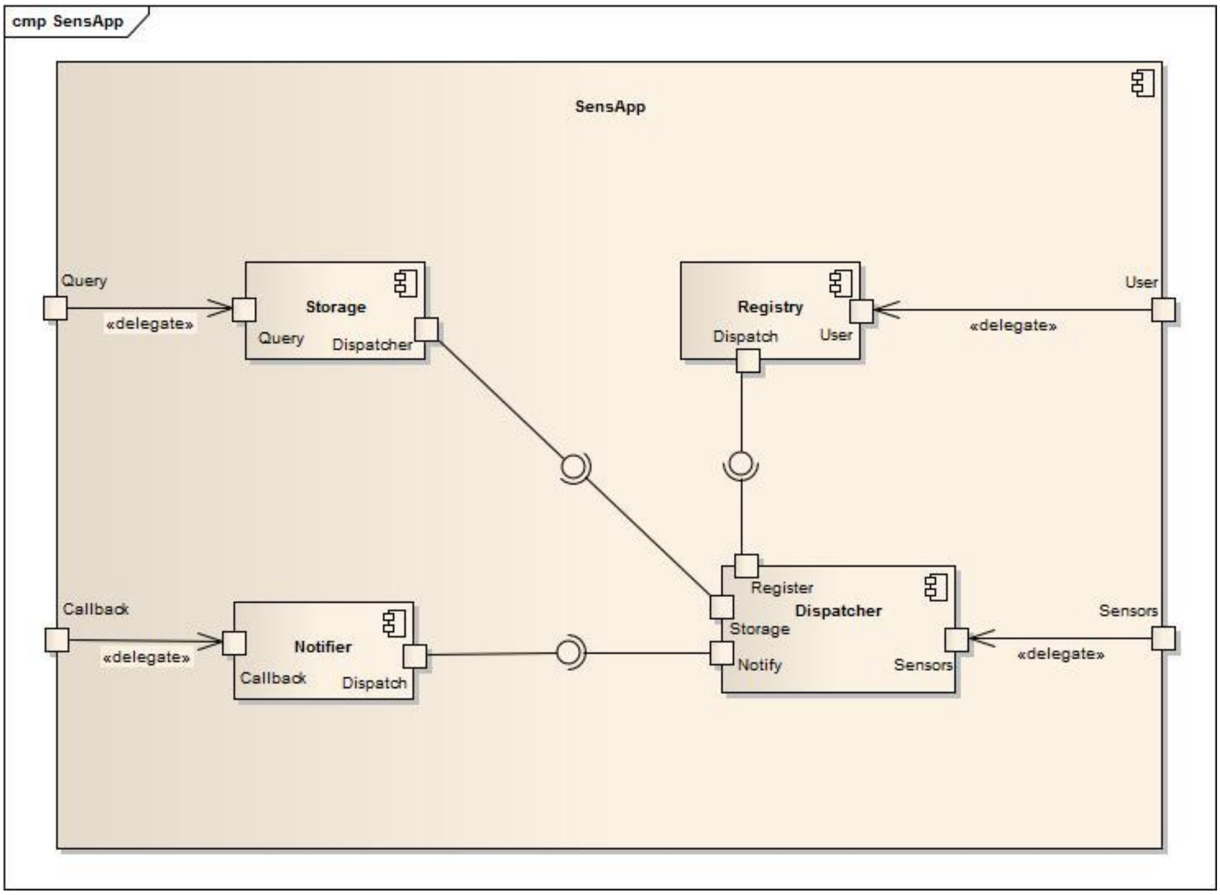

Figure A.1: Component diagram of SensApp

Figure A.2 illustrates the various use cases in the context of SensApp and the stakeholders involved. The sensor architect is responsible for the registration of sensors or for registering sensors. The sensors push data to the application, which indirectly trigger the sending of a notification when relevant data is pushed. The service provider is responsible for the operations and maintenance of the sensors. The data miner can query stored data, while a third party application in addition has the ability to register for notifications when relevant data is pushed.

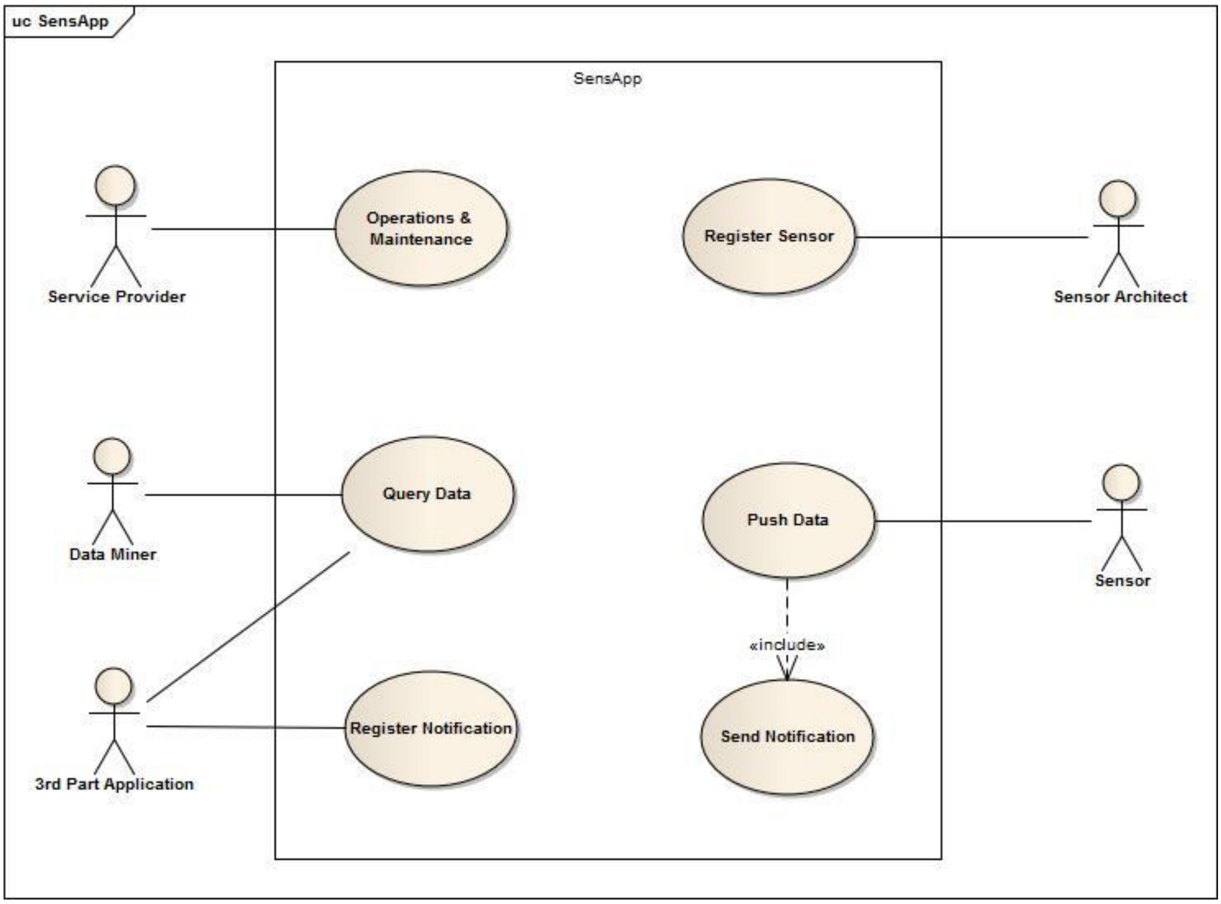

Figure A.2: Use case diagram of SensApp

Figure A.3 illustrates SensApp as a class diagram with various methods involved and the respective relations between the classes. In contrast to Figure A.1, Figure A.3 illustrates the logical behaviour and functionality of the various components of the SensApp application.

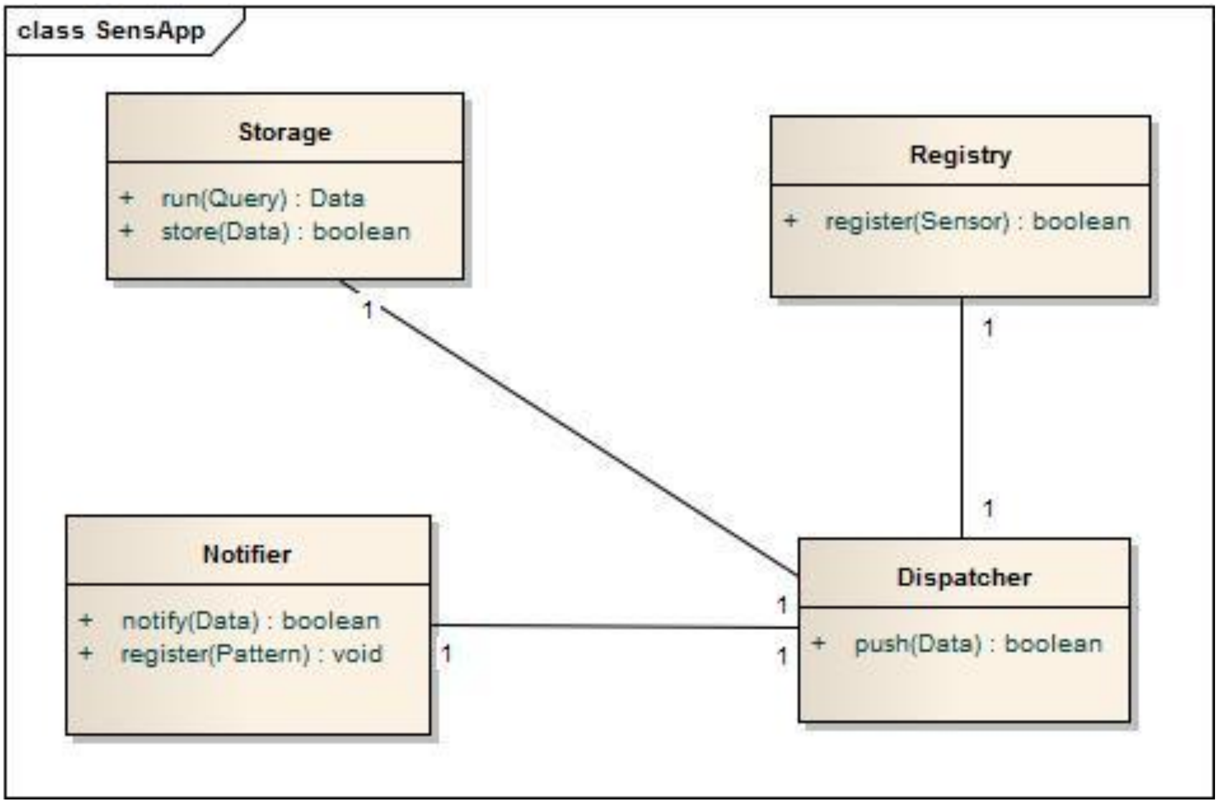

Figure A.3: Class diagram of SensApp

The sequence diagram on Figure A.4 illustrates SensApp in the context of the nursing home scenario, where relevant health data are pushed to SensApp. In this case, SensApp detects a certain pattern and notifies the physician about the abnormal activity.

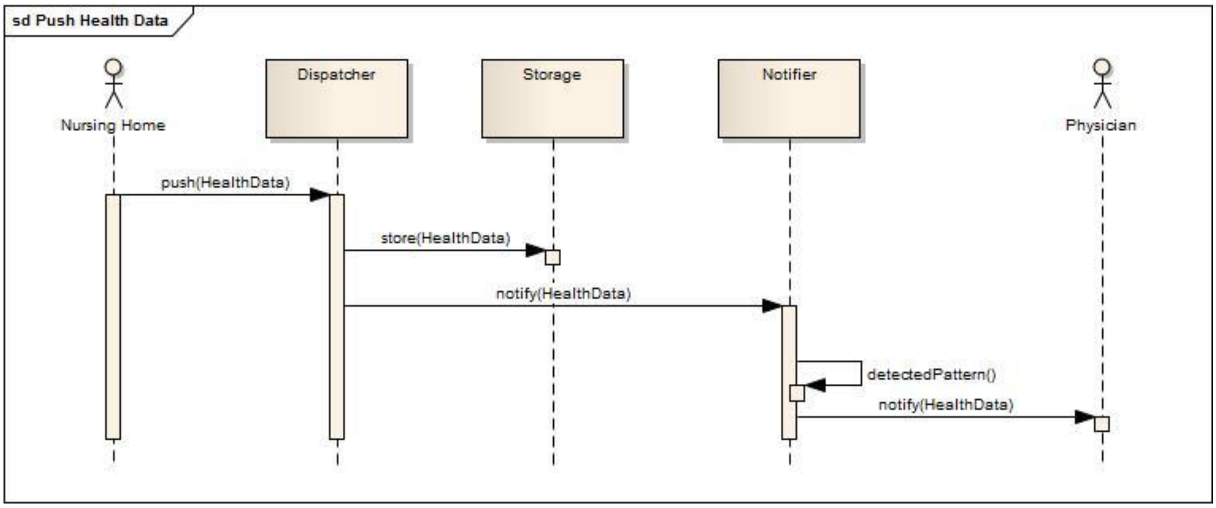

Figure A.4: Sequence diagram based on the example of health data

Figure A.5 illustrates the various use cases in the context of the nursing home scenario and the stakeholders involved. In that manner, Figure A.5 is a more detailed and specified use case diagram compared to Figure A.2. The sensor administrator (labelled sensor architect in Figure A.2) is responsible for registering of sensors. The sensors can push data to the application, which indirectly can trigger the sending of a notification when relevant data is pushed. The service provider is responsible for the operations and maintenance of the sensors. The service provider is also responsible for the education related to the SensApp application. The physician and the patients have the ability to register for notification, check the health status, and provide authorization. When provided authorization by the physician or the patient itself, the next of kin has the ability to register for notification and check the health status of the patient in question.

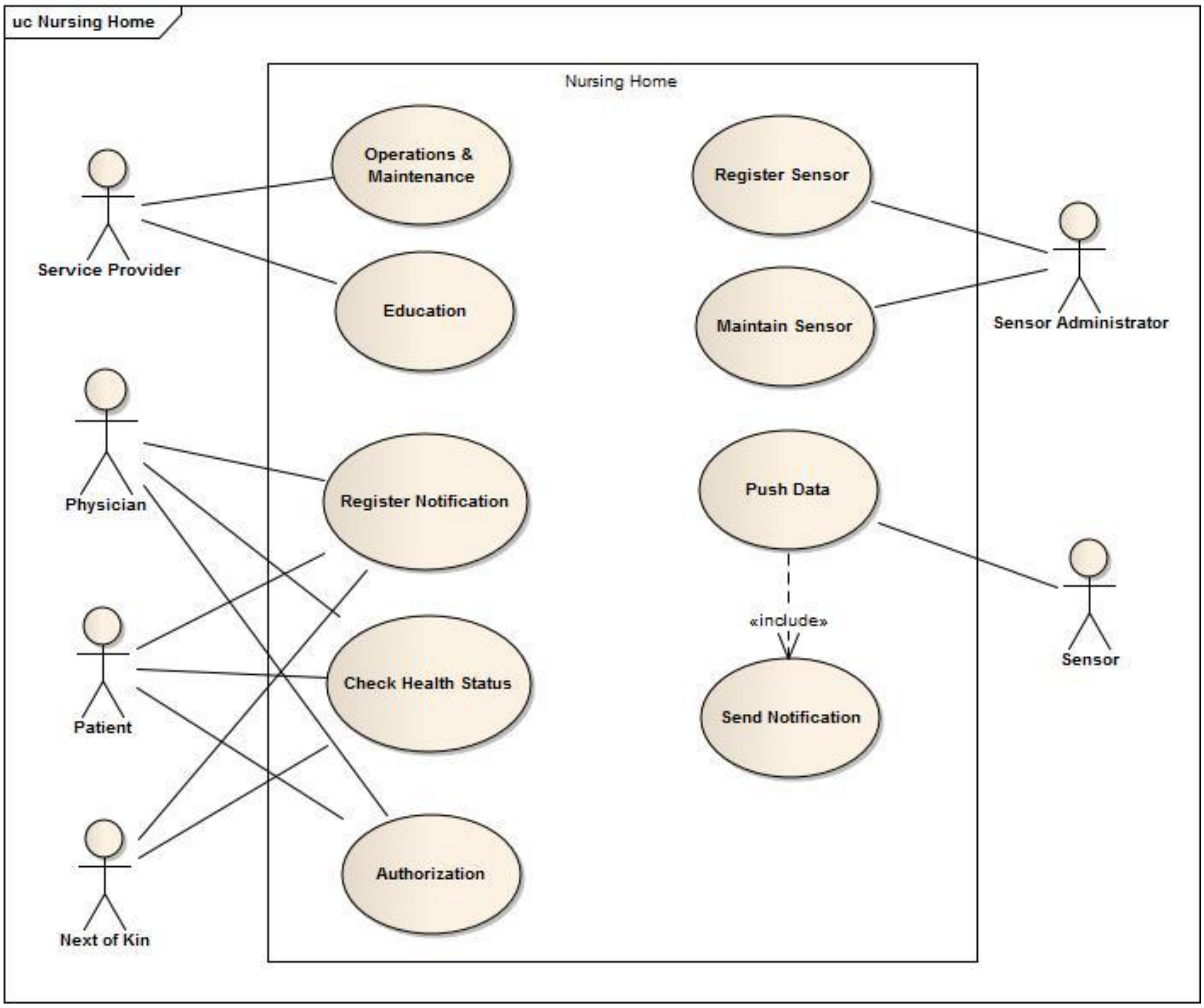

Figure A.5: Use case diagram based on the example of nursing home

Figure A.6 illustrates the sequence of registering a sensor by a sensor administrator. As illustrated by Figure A.1 and A.3, the registration of sensors is maintained by the registry mechanism. The registry receives relevant information by the sensor administrator, such as description about the sensor, creation date etc.

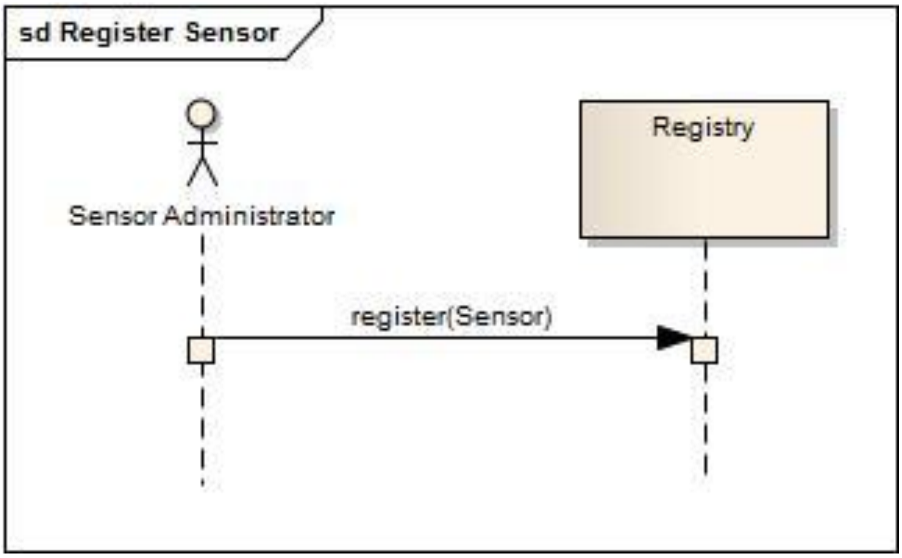

Figure A.6: Register sensor

Figure A.7 illustrates the sequence of registering a pattern by a physician. As illustrated by Figure A.1 and A.3, the registration of notifications is maintained by the notifier. The notifier receives relevant pattern description by the physician.

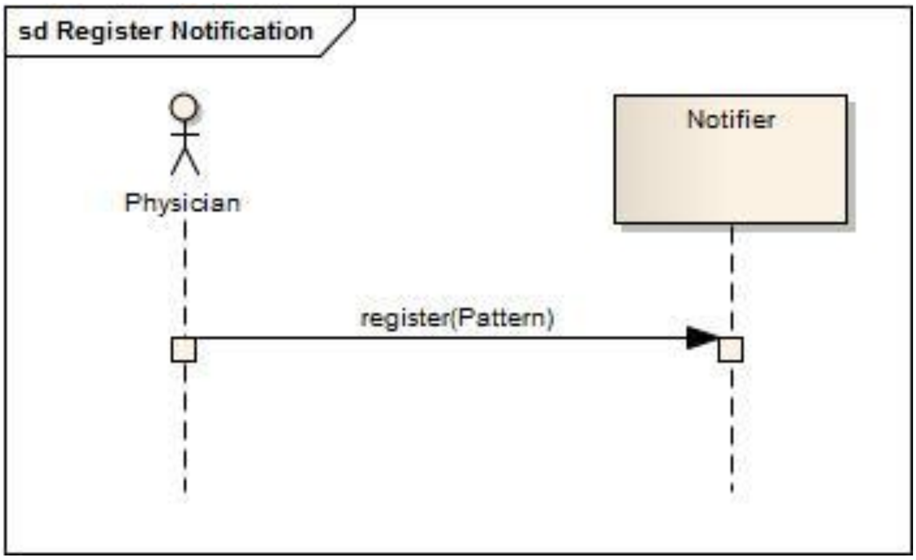

Figure A.7: Register notification

Appendix B

Analysis of SensApp

In this appendix, we present the specification tables that were developed during the analysis of SensApp. The specification tables were developed in close collaboration with the domain experts. The case study was conducted with the objective of improving the security of SensApp. Hence, the specification tables describe the current state of SensApp with respect to cost, risk, and quality aspects. The specification tables represent the input to the process of the decision making method. Table B.1 illustrates the high-level risks associated with SensApp identified by the domain experts.

Table B.1: High-level risks associated with SensApp as is

Who/what causes it?	**How? What is the incident? What does it harm?**	**What makes it possible?**
IT Manager, Administrator	Wrong registration of sensors	(unidentified)
Misconfiguration, intrusion	Illegal access to private data	System not fully secured
Technical configuration, wrong maintenance, wrong design (evaluation), wrong specification of the system	Response time affected (e.g., physician might not be notified on time)	Overload of memory (CPU), scalability problem
Sensor	Misleading and missing pattern detection	(unidentified)
Failure of sensor, network failure	Missing data	Power outage, wrong usage, misconfiguration
(unidentified)	Service (SensApp) out of order	Infrastructure outage
Hacker	DoS-attack, modify data	(unidentified)
Data migration, change in the law, wrong deployment	Legal issue with data localization	Different laws, Intellectual Property Rights (IPR)

Table B.2 illustrates the various quality characteristics associated and required by the SensApp application. The quality characteristics were identified by the domain experts with a brief description of each.

Table B.2: Quality characteristics associated with SensApp as is

#	Quality characteristic	Description
1	Reliability	SensApp should constantly be able to perform its intended and required function on demand.
2	Correctness	Precision and recall of recognition algorithm.
3	Cost of service	Costs related to the operation of the SensApp application.
4	Security of service	Users should be able to have secure access to personal data. Only authorized users should be able to access the data in question. (Integrity, non-repudiation, availability, and confidentiality)
5	Response time	The elapsed time between the initiation of an action and the required response should be satisfactory.
6	Usability	SensApp should provide convenient ease-of-use.
7	Accuracy of data	The accuracy of sensor data provided by SensApp should be close to the true value.
8	Scalability	The SensApp application should be able to perform under expanding workload.

In order to completely understand the SensApp application, it was important to make clear the functional requirements related to SensApp. In that manner, two of the most important functional requirements are presented in Table B.3.

Table B.3: Functional requirements related to SensApp

#	Functional requirement
1	The users of SensApp should be able to sufficiently utilize the sensor data within the context of use.
2	The service should have sufficient system procedures and mechanisms that safeguard confidentiality, integrity, non-repudiation, and availability.

Table B.4 illustrates examples of potential functional or technical changes/modifications that could be implemented within SensApp in order to enhance the security of the system. It is important to emphasize that the proposed changes might have common characteristics.

Table B.4: Examples of functional or technical changes within SensApp

#	Functional/technical changes	Description
1	Change in infrastructure	Infrastructure is defined as the technical base or fundament needed for the functioning of the service provided by SensApp.
2	Change of topology	Topology is defined as the configuration of the technical base or fundament needed for the functioning of the service provided by SensApp.
3	Update software	Update the current software version of SensApp involves implementation of various security mechanisms in the already existing solution of SensApp.
4	Improve recognition algorithm	Implement alternative recognition algorithm for pattern detection.
6	Backup plan	Emergency power aggregator and more frequent backup of data.
7	Change of licenses	Upgrading or purchasing enterprise and commercial software licenses for information security purposes.
8	Change of location	Geographical relocation of the infrastructure, the platform, and the environment that SensApp is based upon.

Table B.5 illustrates the effects on the relevant quality characteristics by implementing change #1 from Table B.4. As illustrated, change in infrastructure will result in different impact on the relevant quality characteristics.

Table B.5: Impact on quality characteristics by implementing change #1

Quality characteristic	Impact
Reliability	Positive – might introduce replication of databases
Cost of service	Negative – operation of SensApp will be more expensive
Security of service	Negative – introduce more complexity
Response time	Positive – might increase response time
Scalability	Positive – more robust to manage expanding workload

Table B.6 illustrates the risks associated with the implementation of change #1 from Table B.4. Change in infrastructure will remove some of the high-level risks associated with SensApp, but will at the same time introduce some new risks related to the specific change.

Table B.6: Risks associated with the implementation of change #1

Who/what causes it?	How? What is the incident? What does it harm?	What makes it possible?
Wrong configuration, wrong budget plan	No money anymore	Cost per hour of the machine
Hacker with malicious intention	Security breach	Increase the number of resources with wrong security policy
Create a node in the wrong place	Wrong localization of data	Various localization for virtual machine in the cloud

Table B.7 illustrates the costs associated with the implementation of change #1 from Table B.4. Change in infrastructure will introduce some new type of costs, and the overall operation of SensApp will be more expensive (also depicted by Table B.5).

Table B.7: Costs associated with the implementation of change #1

Type of cost	Monetary value
Virtual machine cost	Depends on the provider and the type of virtual machine, e.g. EC2 $0.260 per M1 Standard Large (m1.large) Linux/UNIX instance-hour (or partial hours)
Lawyer cost	~500 000 Euros at least
Data transfer	Depends on the provider and the type of virtual machine (e.g. EC2 $0.120 per GB – up to 10 TB/month data transfer out)

The quality requirements were evaluated according to the scale depicted by Figure B.1. Weak achievement of a quality characteristic is represented by 0, while 100 represents superior achievement.

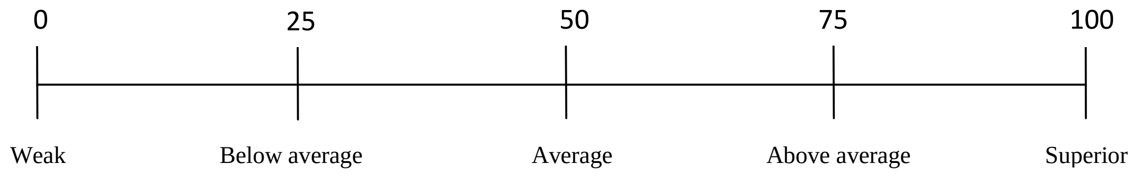

Figure B.1: Quality scale

Table B.8 illustrates the most important quality characteristics related to SensApp. The present value for each of the quality characteristic is presented in terms of the quality scale illustrated by Figure B.1. In addition, the minimal acceptance values for the various characteristics were specified by the domain experts. According to the domain experts, the response time of the current version of SensApp is more than satisfactory.

Table B.8: Quality characteristics related to SensApp

#	Quality characteristic	Description	Present value	Minimal acceptance value
1	Reliability	SensApp should constantly be able to perform its intended and required function on demand.	65	80
2	Response time	The elapsed time between the initiation of an action and the required response should be satisfactory.	75	60
3	Security	Users should be able to have secure access to personal data. Only authorized users should be able to access the data in question.	10	80
4	Accuracy of data	The accuracy of sensor data provided by SensApp should be close to the true value.	50	50/80[1]

Based on the overall objective and requirements, the domain experts identified five potential decision alternatives as illustrated by Table B.9. In contrast to Table B.4, these decision alternatives were identified as the most reasonable in terms of enhancing the security of SensApp. Furthermore, these decision alternatives are assumed to be exclusive and thus involve none or less common characteristics.

[1] The estimates provided by the domain experts are highly dependent on the context and circumstances of the target system under analysis. In that manner, the acceptance value for the various quality characteristics would be higher for vital data (such as medical data) than for other kind of data.

Table B.9: Decision alternatives

#	Decision alternative	Description
A	Change in infrastructure	Infrastructure is defined as the technical base or fundament needed for the functioning of the service provided by SensApp.
B	Change of topology	Topology is defined as the configuration of the technical base or fundament needed for the functioning of the service provided by SensApp.
C	Change of licenses	Upgrading or purchasing enterprise and commercial software licenses for information security purposes.
D	Change of location	Geographical relocation of the infrastructure, the platform, and the environment that SensApp is based upon.
E	Update software	Update the current software version of SensApp involves implementation of various security mechanisms in the already existing solution of SensApp.

Table B.10 describes the various costs related to SensApp. The acceptance value denotes the maximum monetary value that could be spent with respect to each of the cost types. The cost value for software evolution was estimated on the basis of the annual salary of a software developer. The total acceptance value (1105 000 NOK) denotes the total budget of SensApp. However, the present operating cost of SensApp is 715 000 NOK.

Table B.10: Costs related to SensApp

#	Cost type	Description	**Acceptance value** (NOK)	**Present cost** (NOK)
1	Migration	Costs related to service movement	< 30 000	10 000
2	Education	Costs related to personnel education	< 15 000	15 000
3	Licenses	Costs related to new or updated licenses	< 10 000	0
4	Infrastructure	Costs related to infrastructure	< 100 000	70 000
5	Support	Costs related to assistance and support	< 150 000	100 000
6	Software evolution	Costs related to software development and maintenance of SensApp	< 700 000	500 000
7	Other	Unforeseen costs	< 100 000	20 000
	Total =		< 1105 000	715 000

In order to sufficiently perform and execute the decision making method, we needed to understand the acceptance of risk associated with the various decision alternatives. In that manner, we identified possible assets that might be affected by the implementation of the various decision alternatives specified in Table B.9. Each asset is assigned an importance value from 1-5, where 5 being the most important. Table B.11 presents the assets and their importance. The notification service is considered as a less important asset. According to the domain experts, the explanation for this is that if the notification mechanism is unavailable for some reason the user will still be able to query the sensor data.

Table B.11: Assets and importance

Asset	Importance
Dispatcher	4
Storage	5
Notifier	2
Registry	4
Security of data (integrity, non-repudiation, confidentiality, availability)	5
Reliability of SensApp	4

The domain experts identified a consequence scale for the various assets as described in Table B.12. The consequence is considered insignificant if 0-1% of sensor data are affected. However, the consequence is considered catastrophic if 50-100% of sensor data are affected.

Table B.12: Consequence scale

Consequence	Description
Catastrophic	Range of [50%, 100%] of sensor data are affected
Major	Range of [20%, 50%] of sensor data are affected
Moderate	Range of [10%, 20%] of sensor data are affected
Minor	Range of [1%, 10%] of sensor data are affected
Insignificant	Range of [0%, 1%] of sensor data are affected

Similar, the domain experts identified a likelihood scale as described in Table B.13. The likelihood of a vulnerability being exploited is considered as rare if the threat scenario occurs less than once per ten year. The likelihood of a vulnerability being exploited is considered as certain if the threat scenario occurs five times or more per year.

Table B.13: Likelihood scale

Likelihood	**Description**	
Certain	Five times or more per year	[50, ∞] : 10y
Likely	Two to five times per year	[20, 49] : 10y
Possible	Once a year	[6, 19] : 10y
Unlikely	Less than once per year	[2, 5] : 10y
Rare	Less than once per ten year	[0, 1] : 10y

The domain experts provided a risk function for the assets described in Table B.11 (for simplicity we assumed the risk function to be identical for all assets). Considering the risk function depicted in Table B.14, risks covered by green and yellow symbolize acceptance, while risks within the red area should be evaluated for possible treatments.

Table B.14: Risk function

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible					
	Likely					
	Certain					

Appendix C

Specification of decision alternatives

In this appendix, we present the specification tables of the decision alternatives A-E with respect to cost, risk, and quality aspects. The specification tables represent the output gained through Cost Analysis phase, Risk Analysis phase, and Quality Analysis phase. Furthermore, the specification tables of the various decision alternatives represent the input to the Decision Making phase of our process of the decision making method. The specification tables were developed in close collaboration with the domain experts.

Table C.1 illustrates the performance of the various decision alternatives in terms of the quality characteristics specified in Table B.8. The performance was estimated based on the quality scale described by Figure B.1.

Table C.1: Performance of decision alternatives in terms of quality characteristics

Decision alternative	**Reliability** (minimal: 80, present: 65)	**Response time** (60, 75)	**Security** (80, 10)	**Accuracy of data** (50/80, 50)
A	75	75	50	50
B	70	80	40	50
C	60	65	70	50
D	65	75	60	50
E	67	70	85	50

Decision alternative A: Change in infrastructure

Table C.2 illustrates the risks associated with decision alternative A identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk. The likelihood and consequence of a risk is dependent on the importance of data. Hence, the risks are specified based on moderate importance of data.

Table C.2: Risks associated with decision alternative A

#	Risk	Likelihood	Consequence
1	Corruption of data during the replication process. Impact on security of data and storage.	Possible	Catastrophic
2	The data remains in the initial public cloud provider (not erased). Impact on security of the data.	Unlikely	Moderate
3	Someone may intercept data during the replication process due to low security (security breach). Impact on security of the data.	Possible	Major

Table C.3 illustrates the costs related to decision alternative A. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative A.

Table C.3: Costs related to decision alternative A

#	Cost type	Description	Monetary value (NOK)
1	Migration	Costs related to service movement	10 000
2	Education	Costs related to personnel education	15 000
3	Licenses	Costs related to new or updated licenses	0
4	Infrastructure	Costs related to infrastructure	75 000
5	Support	Costs related to assistance and support	100 000
6	Software evolution	Costs related to software development and maintenance of SensApp	500 000
7	Other	Unforeseen costs	20 000
	Total =		720 000

Table C.4 illustrates the risk function related to decision alternative A. Risk #1 and #3 from Table C.2 appear within the red area of the risk function and are therefore considered to be unacceptable.

Table C.4: Risk function related to decision alternative A

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely			**2**		
	Possible				**3**	**1**
	Likely					
	Certain					

Decision alternative B: Change of topology

Table C.5 illustrates the risks associated with decision alternative B identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk. The likelihood and consequence of a risk is dependent on the importance of data. Hence, the risks are specified based on moderate importance of data.

Table C.5: Risks associated with decision alternative B

#	Risk	Likelihood	Consequence
1	Interception of data during the migration process. Impact on security of the data.	Possible	Major
2	Increased number of communication nodes. Impact on security of the data.	Possible	Major

Table C.6 illustrates the costs related to decision alternative B. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative B.

Table C.6: Costs related to decision alternative B

#	Cost type	Description	**Monetary value** (NOK)
1	Migration	Costs related to service movement	10 000
2	Education	Costs related to personnel education	15 000
3	Licenses	Costs related to new or updated licenses	0
4	Infrastructure	Costs related to infrastructure	80 000
5	Support	Costs related to assistance and support	105 000
6	Software evolution	Costs related to software development and maintenance of SensApp	500 000
7	Other	Unforeseen costs	30 000
	Total =		740 000

Table C.7 illustrates the risk function related to decision alternative B. Risk #1 and #2 from Table C.5 appear within the red area of the risk function and are therefore considered to be unacceptable.

Table C.7: Risk function related to decision alternative B

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible				**1, 2**	
	Likely					
	Certain					

Decision alternative C: Change of licenses

Table C.8 illustrates the risks associated with decision alternative C identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk. The likelihood and consequence of a risk is dependent on the importance of data. Hence, the risks are specified based on moderate importance of data.

Table C.8: Risks associated with decision alternative C

#	**Risk**	**Likelihood**	**Consequence**
1	Compatibility issues and problems between our tools and third party tools. Impact on all services (dispatcher, storage, notifier, and registry).	Likely	Moderate
2	Lack of control on the security of the system. Impact on security of the data.	Unlikely	Major

Table C.9 illustrates the costs related to decision alternative C. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative C.

Table C.9: Costs related to decision alternative C

#	**Cost type**	**Description**	**Monetary value** (NOK)
1	Migration	Costs related to service movement	0
2	Education	Costs related to personnel education	20 000
3	Licenses	Costs related to new or updated licenses	25 000
4	Infrastructure	Costs related to infrastructure	75 000
5	Support	Costs related to assistance and support	120 000
6	Software evolution	Costs related to software development and maintenance of SensApp	500 000
7	Other	Unforeseen costs	30 000
	Total =		770 000

Table C.10 illustrates the risk function related to decision alternative C. Risk #1 from Table C.8 appear within the red area of the risk function and are therefore considered to be unacceptable.

Table C.10: Risk function related to decision alternative C

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely				**2**	
	Possible					
	Likely			**1**		
	Certain					

Decision alternative D: Change of location

Table C.11 illustrates the risks associated with decision alternative D identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk. The likelihood and consequence of a risk is dependent on the importance of data. Hence, the risks are specified based on moderate importance of data.

Table C.11: Risks associated with decision alternative D

#	Risk	Likelihood	Consequence
1	Hardware software failure. Impact on security of the data.	Possible	Major
2	Hardware failure. Impact on registry and storage.	Possible	Minor
3	Hardware failure. Impact on dispatcher and notifier.	Possible	Major
4	Interception of data. Impact on security of the data.	Possible	Major

Table C.12 illustrates the costs related to decision alternative D. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative D.

Table C.12: Costs related to decision alternative D

#	**Cost type**	**Description**	**Monetary value** (NOK)
1	Migration	Costs related to service movement	30 000
2	Education	Costs related to personnel education	20 000
3	Licenses	Costs related to new or updated licenses	0
4	Infrastructure	Costs related to infrastructure	150 000
5	Support	Costs related to assistance and support	100 000
6	Software evolution	Costs related to software development and maintenance of SensApp	550 000
7	Other	Unforeseen costs	40 000
	Total =		890 000

Table C.13 illustrates the risk function related to decision alternative D. Risk #1, #3, and #4 from Table C.11 appear within the red area of the risk function and are therefore considered to be unacceptable.

Table C.13: Risk function related to decision alternative D

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible		**2**		**1, 3, 4**	
	Likely					
	Certain					

Decision alternative E: Update software

Table C.14 illustrates the risks associated with decision alternative E identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk. The likelihood and consequence of a risk is dependent on the importance of data. Hence, the risks are specified based on moderate importance of data.

Table C.14: Risks associated with decision alternative E

#	**Risk**	**Likelihood**	**Consequence**
1	Interception of data. Impact on security of the data.	Likely	Major
2	Hosts down after software update (bugs, software problems etc.). Impact on dispatcher and notifier.	Likely	Major
3	Hosts down after software update (bugs, software problems etc.). Impact on storage and registry.	Likely	Moderate

Table C.15 illustrates the costs related to decision alternative E. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative E.

Table C.15: Costs related to decision alternative E

#	**Cost type**	**Description**	**Monetary value** (NOK)
1	Migration	Costs related to service movement	0
2	Education	Costs related to personnel education	20 000
3	Licenses	Costs related to new or updated licenses	0
4	Infrastructure	Costs related to infrastructure	70 000
5	Support	Costs related to assistance and support	125 000
6	Software evolution	Costs related to software development and maintenance of SensApp	600 000
7	Other	Unforeseen costs	40 000
	Total =		855 000

Table C.16 illustrates the risk function related to decision alternative E. Risk #1 and #2 from Table C.14 appear within the red area of the risk function and are therefore considered to be unacceptable.

Table C.16: Risk function related to decision alternative E

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible					
	Likely			**3**	**1, 2**	
	Certain					

Appendix D

Outcome of Decision Making phase

In this appendix, we present the outcome of the Decision Making phase. We developed a prototype tool for modeling the decision alternatives and estimating their impacts. The tool is based on Microsoft Office Excel and stores all quantitative input. The tool facilitates phase 4 by defining the selection criteria and enabling propagation of impacts of the input on the overall performance.

The domain experts assigned each of the quality characteristics in Table C.1 a weight according to the quality scale specified by Figure B.1. In order to calculate total quality values for each decision alternative, there was a need for normalization. Table D.1 is therefore based on Table C.1 and is a result of the Decision Making phase. The normalized weights were calculated by the domain experts as follows: $\frac{weight}{sum\ of\ weights}$. In that manner, the normalized weight for reliability is $\frac{80}{80+75+85+70} \approx 0{,}3$.

Table D.1: Quality characteristics and normalized weight values

Decision alternative	**Reliability** (minimal: 80, present: 65)	**Response time** (60, 75)	**Security** (80, 10)	**Accuracy of data** (50/80, 50)
A	75	75	50	50
B	70	80	40	50
C	60	65	70	50
D	65	75	60	50
E	67	70	85	50
Weight [1…100]	***80***	***75***	***85***	***70***
Normalized weight	*0,3*	*0,2*	*0,3*	*0,2*

Table D.2 illustrates the risk values specified by the domain experts. The risk values were specified in the range of 0-100, where 100 is considered as critical. The risk values were specified in order to generate and calculate the total weight of risks for each decision alternative. According to Table D.2, the total risk value is 1347.

Table D.2: Risk function with specified risk values

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*	0	11	25	74	80
	Unlikely	2	15	30	79	84
	Possible	4	20	75	85	92
	Likely	8	21	83	90	97
	Certain	10	82	87	93	100

Table D.3 illustrates the risk values associated with decision alternative A. A risk value is assigned for a risk related to each impacted asset. Risk #1 (see Table C.2) has an impact on both security of data and the storage mechanism. In that manner, we generate a risk value for each impacted asset.

Table D.3: Risk values associated with decision alternative A

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely			30		
	Possible				85	92, 92
	Likely					
	Certain					

Table D.4 illustrates the risk values associated with decision alternative B. A risk value is assigned for a risk related to each impacted asset.

Table D.4: Risk values associated with decision alternative B

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible				85, 85	
	Likely					
	Certain					

Table D.5 illustrates the risk values associated with decision alternative C. A risk value is assigned for a risk related to each impacted asset. Risk #1 (see Table C.8) has an impact on the dispatcher, the notifier, the registry, and the storage mechanism. In that manner, we generate a risk value for each impacted asset.

Table D.5: Risk values associated with decision alternative C

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely				79	
	Possible					
	Likely			83, 83, 83, 83		
	Certain					

Table D.6 illustrates the risk values associated with decision alternative D. A risk value is assigned for a risk related to each impacted asset. In that manner, we generate a risk value for each impacted asset.

Table D.6: Risk values associated with decision alternative D

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible		20, 20		85, 85, 85, 85	
	Likely					
	Certain					

Table D.7 illustrates the risk values associated with decision alternative E. A risk value is assigned for a risk related to each impacted asset. In that manner, we generate a risk value for each impacted asset.

Table D.7: Risk values associated with decision alternative E

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible					
	Likely			83, 83	90, 90, 90	
	Certain					

Table D.8 illustrates the overall performance of the decision alternatives in terms of cost, risk, and quality. Total quality denotes the total quality score achieved by each decision alternative. The aggregation function for total quality is as follows: $a \cdot Q1 + b \cdot Q2 + c \cdot Q3 + d \cdot Q4$, where a, b, c, and d denotes the normalized weight for the relevant quality characteristic. The total quality achieved by decision alternative A is therefore $0{,}3 \cdot 75 + 0{,}2 \cdot 75 + 0{,}3 \cdot 50 + 0{,}2 \cdot 50 \approx 62{,}5$. Weight of risks is calculated by summarizing the risk values for the relevant decision alternative. Cost of one point of quality is generated as follows: $\frac{total\ cost}{total\ quality}$. Similarly, risk of one point of quality is generated as follows: $\frac{weight\ of\ risks}{total\ quality}$. Table D.8 also specifies the number of catastrophic risks associated with the relevant decision alternative.

Table D.8: Overall performance of the decision alternatives

Decision alternative	**Total cost** (total budget: NOK 1105 000)	**Total quality**	**Weight of risks**	**Cost of one point of quality**	**# of catastrophic risk**	**Risk of one point of quality**
A	720 000	62,5	269	11520,0	2	4,3
B	740 000	59,7	170	12400,0	0	2,8
C	770 000	61,7	411	12481,0	0	6,7
D	890 000	62,7	380	14203,3	0	6,1
E	855 000	68,8	436	12423,2	0	6,3

Appendix E

Results of thought experiment

In this appendix, we present the results from the thought experiment. The thought experiment was conducted with objective to evaluate and validate the estimates provided by the domain experts.

Thought experiment 1

The first thought experiment involved the introduction of a new decision alternative F – backup of SensApp. The question in this case was: How will decision alternative F perform compared with decision alternatives A-E in terms of cost, risk, and quality aspects? In that manner, Table E.1 illustrates the risks associated with decision alternative F identified by the domain experts. In addition, the impacted assets are specified with respect to the relevant risk.

Table E.1: Risks associated with decision alternative F

#	Risk	Likelihood	Consequence
1	Access of backup data. Impact on the security of data.	Possible	Major
2	Access of backup data during synchronization process. Impact on security of data.	Possible	Major
3	Corruption of data during synchronization process. Impact on security of data.	Possible	Moderate
4	Failure during the synchronization process. Impact on database.	Likely	Moderate

Table E.2 illustrates the costs related to decision alternative F. The total monetary value given denotes the total operating cost of SensApp after the implementation of decision alternative F.

Table E.2: Costs related to decision alternative F

#	Cost type	Description	Monetary value (NOK)
1	Migration	Costs related to service movement	30 000
2	Education	Costs related to personnel education	0
3	Licenses	Costs related to new or updated licenses	0
4	Infrastructure	Costs related to infrastructure	150 000
5	Support	Costs related to assistance and support	100 000
6	Software evolution	Costs related to software development and maintenance of SensApp	650 000
7	Other	Unforeseen costs	40 000
	Total =		970 000

Table E.3 illustrates the risk function and the associated risk values related to decision alternative F. A risk value is assigned for a risk related to each impacted asset.

Table E.3: Weight of risks associated with decision alternative F

		Consequence				
		Insignificant	*Minor*	*Moderate*	*Major*	*Catastrophic*
Likelihood	*Rare*					
	Unlikely					
	Possible			75	85, 85	
	Likely			83		
	Certain					

Table E.4 illustrates the performance of decision alternative F compared with decision alternatives A-E in terms of quality characteristics. Decision alternative F performs excellent in terms of reliability and response time, but average when it comes to security and accuracy of data.

Table E.4: Performance of decision alternative F in terms of quality characteristics

Decision alternative	**Reliability** (minimal: 80, present: 65)	**Response time** (60, 75)	**Security** (80, 10)	**Accuracy of data** (50/80, 50)
A	75	75	50	50
B	70	80	40	50
C	60	65	70	50
D	65	75	60	50
E	67	70	85	50
F	**80**	**75**	**50**	**50**
Weight [1…100]	*80*	*75*	*85*	*70*
Normalized weight	*0,3*	*0,2*	*0,3*	*0,2*

Table E.5 illustrates the overall performance of decision alternative F compared with decision alternatives A-E in terms of cost, risk, and quality aspects. Decision alternative F is the most expensive alternative with respect to cost of one point of quality.

Table E.5: Overall performance of decision alternative F

Decision alternative	**Total cost** (total budget: NOK 1105 000)	**Total quality**	**Weight of risks**	**Cost of one point of quality**	**# of catastrophic risk**	**Risk of one point of quality**
A	720 000	62,5	269	11520,0	2	4,3
B	740 000	59,7	170	12400,0	0	2,8
C	770 000	61,7	411	12481,0	0	6,7
D	890 000	62,7	380	14203,3	0	6,1
E	855 000	68,8	436	12423,2	0	6,3
F	**970 000**	**63,8**	**328**	**15206,1**	**0**	**5,1**

Thought experiment 2

The second thought experiment involved the impact on cost by implementing two operational environments instead of one. The questions in this case was: What will be the impact on the total cost for decision alternative E, and what will be the impact on the individual cost factors for the decision alternative E? In that manner, Table E.6 illustrates the impact on the total cost for decision alternative E by implementing two operational environments instead of one. The domain experts provided input to both Table E.6 and E.7 during thought experiment 2.

Table E.6: Impact on the total cost for decision alternative E

Decision alternative	**Present total cost** (NOK)	**New total cost** (NOK)
A	720 000	860 000
B	740 000	900 000
C	770 000	835 000
D	890 000	1050 000
E	**855 000**	**1000 000**

Table E.7 illustrates the impact on the individual cost factors for decision alternative E. Compared with Table E.6, the evaluation based on the individual cost factors provide a more detailed estimation of the various costs.

Table E.7: Impact on the individual cost factors for decision alternative E

#	Cost type	Description	Present monetary value (NOK)	New monetary value (NOK)
1	Migration	Costs related to service movement	0	0
2	Education	Costs related to personnel education	20 000	20 000
3	Licenses	Costs related to new or updated licenses	0	0
4	Infrastructure	Costs related to infrastructure	70 000	100 000
5	Support	Costs related to assistance and support	125 000	150 000
6	Software evolution	Costs related to software development and maintenance of SensApp	600 000	850 000
7	Other	Unforeseen costs	40 000	60 000
	Total =		855 000	1180 000

Thought experiment 3

The third thought experiment involved the impact of increasing the weight of security to 95. The question in this case was: Which decision alternative do you think will be the most desirable one, if we increase the weight of security to 95? In that manner, Table E.8 illustrates the impact of increasing the weight of security to 95 in terms of normalized weight for decision alternative A-E.

Table E.8: Impact of thought experiment 3

Decision alternative	**Reliability** (minimal: 80, present: 65)	**Response time** (60, 75)	**Security** (80, 10)	**Accuracy of data** (50/80, 50)
A	75	75	50	50
B	70	80	40	50
C	60	65	70	50
D	65	75	60	50
E	67	70	85	50
Weight [1…100]	*80*	*75*	*95*	*70*
Normalized weight	*0,3*	*0,2*	*0,3*	*0,2*

Table E.9 illustrates the overall impact of increasing the weight of security to 95. Compared with Table E.5, the results have been none or little affected by increasing the weight of security.

Table E.9: Overall impact of thought experiment 3

Decision alternative	**Total cost** (total budget: NOK 1105 000)	**Total quality**	**Weight of risks**	**Cost of one point of quality**	**# of catastrophic risk**	**Risk of one point of quality**
A	720 000	62,1	269	11592,5	2	4,3
B	740 000	59,1	170	12529,1	0	2,9
C	770 000	62,0	411	12428,8	0	6,6
D	890 000	62,6	380	14222,2	0	6,1
E	855 000	69,3	436	12332,7	0	6,3

Thought experiment 4

The fourth thought experiment involved the impact of decreasing the value of security of decision alternative E to 60 and increasing the weight of reliability to 85. The question in this case was: Which decision alternative do you think will be the most desirable one, if we decrease the value of security of decision alternative E and increase the weight of reliability? In that manner, Table E.10 illustrates the impact of decreasing the value of security of decision alternative E to 60 and increasing the weight of reliability to 85 in terms of normalized weight for decision alternative A-E.

Table E.10: Impact of thought experiment 4

Decision alternative	**Reliability** (minimal: 80, present: 65)	**Response time** (60, 75)	**Security** (80, 10)	**Accuracy of data** (50/80, 50)
A	75	75	50	50
B	70	80	40	50
C	60	65	70	50
D	65	75	60	50
E	67	70	60	50
Weight [1…100]	*85*	*75*	*85*	*70*
Normalized weight	*0,3*	*0,2*	*0,3*	*0,2*

Table E.11 illustrates the overall impact of decreasing the value of security of decision alternative E to 60 and increasing the weight of reliability to 85. Compared with thought experiment 3, the estimates have been more affected in this case.

Table E.11: Overall impact of thought experiment 4

Decision alternative	**Total cost** (total budget: NOK 1105 000)	**Total quality**	**Weight of risks**	**Cost of one point of quality**	**# of catastrophic risk**	**Risk of one point of quality**
A	720 000	62,7	269	11483,5	2	4,3
B	740 000	59,8	170	12366,0	0	2,8
C	770 000	61,7	411	12486,5	0	6,7
D	890 000	62,7	380	14194,9	0	6,1
E	855 000	62,0	436	13779,7	0	7,0

Appendix F

The written evaluation template

The written evaluation feedback form that was handed out during the last meeting (see Section 6.2) and filled out by the domain experts was as follows:

Evaluation of the Decision Making Process in the SensApp Case Study

We need your feedback in order to further improve the decision making process. We will therefore be very thankful if you could please provide your answers and comments to the following questions.

1. Please specify your background and role in the case study:
   - Work place:
   - Position:
   - Education (degree):
   - Years of professional experience:
   - Role in the case study:
2. What is your general impression of the decision making process? Please describe the experience from the case study in your own words. What do you think are strengths and weaknesses of the decision making process?
3. To what degree do you think the decision making process facilitates specification of decision criteria and trade-off analysis?
4. What is your experience from the decision making process undergone? We are particularly interested in your opinion regarding the effort needed to specify the relevant aspects, and conduct an analysis.
5. To what degree to you think the decision making process provide structured guidance and support for informed decision making in real-life setting within limited resources?
6. Please comment on your opinion regarding understandability, completeness, and usability of the models:
7. To what degree do you think the decision making process can aid and facilitate understanding in decision making scenarios?
8. What do you see as the main challenges or problems with usage of the decision making process?
9. What do you see as the main benefits of the decision making process?
10. What kinds of improvements of the decision making process would you recommend?
11. Do you have further comments or suggestions?

Appendix G

The written feedback

In this appendix, we present the written feedback received from the two respondents – R1 and R2 respectively.

Question 2

R1: I believe that this decision-making process is an interesting endeavor in merging cost/quality trade-off with risk analysis. A potential weakness could be the uncertainty which pertains to the provided input. The impact that such an uncertainty has on the resulting decisions is not clear to me, and it probably lowers the confidence one may have on them.

R2: I believe the process is interesting and meaningful. Maybe it could have been interesting to request some preparation works from us in order to identify some risks, and decision alternatives so that we could have been more confident in the proposed solutions. Another point which was disturbing was the lack of confidence in the numbers we have presented, maybe providing us some average numbers could help us.

Question 3

R1: It provides an opportunity to see, side-by-side, numbers quantifying, cost, quality and risk. To the best of my knowledge, such an analysis covering risk has never been proposed in the Software Engineering community.

R2: Being aware of the relationships between all assets, decisions, risks, costs… is not an easy task. With respect to this I really believe the proposed decision making process is helpful.

Question 4

R1: The assumption that the design alternatives are exclusive, may seems the less realistic part of process. From the Software Engineering standpoint, I believe it would be more relevant to identify a set of possible actions with their respective impact on risk, quality and cost, and to generate all possible combinations (i.e., design alternatives). I believe the large number of possible combinations is also one of the key factors, which prevents designer to look carefully at all alternatives.

R2: I think the most disturbing point was the lack of confidence in the risks, decisions and costs we proposed.

Question 5

R1: I think this process provides a clear hindsight about what decisions could be relevant, with respect to given objective. To me, the key point is to put this in perspective of the uncertainty of the inputs, and the completeness of the design alternatives, which were identified up-front.

R2: I think the process is really meaningful when it comes to identify relationships between all elements (risks, consequence, costs, decisions...).

Question 6

R1: To my opinion, the two weakest aspects of the process are the definition of time and the completeness of the design alternatives identified in the first place. As far as I understand, time is a key factor here. The time spent implementing a given design alternative obviously impacts the cost, the risk, and the quality of the resulting system. It was not clear to me how we discriminated between a punctual yet very risky design alternative, and, for instance, a long lasting but less risky design alternative. Regarding the completeness of the set of design alternatives, I believe it may be relevant to build this set from a set of atomic change performed on the systems. I mentioned it in question # 4.

R2: The process was quite easy to follow.

Question 7

R1: I believe it help thinking about key questions regarding risks, cost, and quality, which would be otherwise overlooked.

R2: -

Question 8

R1: One piece of information that could be helpful for such a decision process is extent the best to which the best decision is distinguished from the other. For instance, if the overall evaluation of the best decision is not significantly higher, one may want to check to which all decisions lays in somewhat the same range.

R2: Identifying the risks and decision alternatives. For us: identifying the costs. Identifying the methods to select the best alternatives.

Question 9

R1: To my opinion, the main benefit is to make explicit the rationales behind a given choice. In the context of software evolution, where decisions will be stacked over the time, it would be very useful to check whether new decisions do not break the initial objectives.

R2: It proposes a structured approach that helps in identifying the relevant aspects and relationships between all elements of the study.

Question 10

R1: As I already mentioned a few, here is some sort of summary. I would retain the three following directions of improvements: i) quantification of the uncertainty, ii) being time dependent, and iii) quantifying some sort of "distance" between the best decision and the others.

R2: It could be interesting to add some degree of uncertainty to the values proposed. For instance, for the budget, costs defining some intervals of probabilities may help in the selection of the best alternative. Sometimes, propose some average values.

Question 11

R1: No

R2: -